CHALMERS
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# Performance Evaluation of a Drinking Water Treatment Plant in Samaipata, Bolivia

Master's Thesis in Infrastructure and Environmental Engineering

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Department of Architecture and Civil Engineering
*Water Environment Technology*
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Master’s Thesis ACEX30-19-95
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Cover: Sand and activated carbon filters of the treatment plant in Samaipata. Author's copy right. April 9th, 2018 (Author's own copyright)

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# Abstract

Unsafe water and a lack of basic sanitation causes nearly 80 percent of all sicknesses and diseases in the world. The provision of safe drinking water on community water level, especially in Bolivia one of the poorest countries of South America, faces major challenges in regard of a lack of investment in the water and sanitation sector, in the conditions of the water infrastructure, and of public appreciation for the value of water.

A drinking water treatment plant for a population of 4,935 inhabitants in Samaipata in Bolivia was evaluated in terms of performance, design, operation, and maintenance. The thesis aimed to identify technical problems and deficiencies in operation of the plant, and to introduce suitable treatment measures for the source El Fuerte and the well La Carretera to the responsible Water Cooperative of the village. The risk of contamination for both sources was assessed by a protocol for sanitary facilities. Water samples were taken to identify whether suitable treatment technologies for the types of water source are provided. The performance of each treatment step in the plant was studied by inspection and water analyses at different points in the treatment chain. Jar tests were performed with $Al_2(SO_4)_3$, $Al_2(SO_4)_3$ and lime, $FeCl_3$ and $FeSO_4$. The plant was operated for 4.5 h with an increased dosage of 15 mg/l of Aluminum Sulfate. A Microbial Barrier Analysis (MBA) and Quantitative Microbial Risk Assessment (QMRA) were performed to assess the health risk based on the Water Safety Plan concept.
Less source protection, lack of skilled expertise in operation, deficiency of guidance from the administration, insufficient design and equipment, and incomplete technologies are identified as the main issues in this study. Recommendations in a two-step implementation plan are presented to provide of an adequate water supply in Samaipata.

*Keywords:* Bolivia; Developing Countries; Drinking Water; Health Risk Assessment; Jar Test; Maintenance; MBA; Operation; Performance Evaluation; QMRA; Samaipata; Turbidity; Water Cooperative; Water Quality; Water Treatment Plant.

# Preface

Michaela Karolina Braun, 2019

First of all, I would like to take this opportunity to thank all those who supported and motivated me during the development of this master thesis in Bolivia.

This report concludes my studies in the Master of Science double degree program Infrastructure and Environmental Engineering (Chalmers University of Technology) and Water Resources Engineering and Management (University of Stuttgart). I would like to thank everyone who made this project possible. A special thanks to my supervisors Thomas Pettersson, my two examiners Sebastien Rauch, and Ralf Minke and the WAREM course director Anne Weiss for their support and guidance during this process.

My sincere thanks to the Water Cooperative and residents of Samaipata. Thank you for the possibility to acquire my thesis with you in a short time. Moreover, I would like to thank for the provision of data for my thesis. In this behalf, I also want to thank Margot Franken and Melissa Crane Powers.

In addition, I am profoundly grateful to the staff and students of the Universidad Mayor de San Simón in Cochabamba. My research would have been impossible without the aid and support of Alvaro Mercado, Ana Maria Romero, and Claudia Cossio Grageda. Thank for providing the time and assistance to work with me on this project. I will always remember their hospitality.

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Finally, I must express my gratitude to my family and friends for supporting me and continuously motivating me throughout the years of study and through the process of writing this thesis. In particular, I want to thank my parents, this achievement would not have been possible without them.

Thank you, all of you!

# Contents

# Nomenclature

**Acronyms**

ALUM – Aluminum Sulfate

B – Bacteria

BOD - Biochemical Oxygen Demand

BOM - Biodegradable Organic Matter

BSF – Bio Sand Filtration

CASA - Centro de Agua y Saneamiento Ambiental

CFS Tank – Coagulation Flocculation and Sedimentation Tank

FG – Casted Iron

GAC - Granular Activated Carbon

HAAs - Halo Acetic Acids

HRF – Flow Roughing Filtration

MBA - Microbial Barrier Analysis

MDG - Millennium Development Goals

MF - Microfiltration

NF - Nanofiltration

NGO - Non-Governmental Organization

NGO APEP - Asociación Para la Erradicación de la Pobreza

No – Evaluation of the question of the risk of contamination protocol with No

O&M - Operation and Maintenance

P – Protozoa

QMRA - Microbial Risk Assessment

RO - Reserve Osmosis

SODIS - Solar Drinking Water Disinfection Systems

SSF - Slow Sand Filtration

THM - Trihalomethane

TSS - Total Suspended Solids

UF - Ultrafiltration

V – Viruses

w/ - with

w/o – without

WTP – Water Treatment Plant

# 1. Introduction

Under the Millennium Development Goals (MDGs) context, different global challenges have been successfully realized throughout the framework analysis period. In the year 2010, the target for water access was reached, when more than 90 % of the world population had access to drinking water improved sources. Nevertheless, approximately 10 % of the world's population – 663 million people – still drink water from unimproved drinking water sources (UNICEF, 2017).

Inadequate sanitation can spread illnesses easily. The World Health Organization (2017) stated that unsafe drinking water, along with poor treatment and hygiene, are the main contributors to an estimated 4 billion cases of diarrheal disease annually, causing more than 1.5 million deaths, mostly among kids under 5 years of age.

Water treatment, especially in developing countries, faces major challenges in terms of a lack of investment in the water and sanitation sector, ill-defined institutional frameworks, capacity, limitations, and neglect of rural areas (Nhapi I., 2015). In contrast to developed countries, economies are weaker, and infrastructure is not as developed. Often conventional drinking water treatments, such as in developed countries, are often unsuitable for these cases. More effort must be done in order to reach the global goal of increasing access to improved sanitation in these parts of the world (Andersson, Dickin, & Rosemarin, 2016).

## 1.1 Aim and objective

The main goal of this thesis is to improve the water quality of the drinking water treatment plant in Samaipata in Bolivia to comply with recommended values for drinking water standards.
During this study, the drinking water treatment plant will be evaluated in terms of performance, design, operation, and maintenance. The water quality from the sources and during the treatment steps in the plant will be analyzed. The outcome of the study shall identify technical problems and deficiencies in operation in the plant and introduce suitable treatment measures for the water sources to the responsible Water Cooperative of the village.
The result of this study shall lead to an enhancement of the living conditions of the people and provide a proposal of measurements for a safe water consumption in Samaipata.

## 1.2 Delimitations

Due to a general scar amount of plans and documentation of the drinking water treatment plant and the existing water system, the data collection in this study is mainly based on interviews and personal conversations with the Water Cooperative and residents of Samaipata. The responsible construction company still did not send all the relevant papers for the plant, which are crucial for adequate operation and to understand the decision-making for certain dosages and design parameters.
Knowledge of certain details and locations about the distribution system is kept without documentation only by the technicians, which are working at the system. It needs to be pointed out that during some interviews answers have been expressed quite uncertain or were changing from day to day of questioning, which are used as assumptions of several calculations.
During the plant visit, some processes such as the sand and activated carbon filters in the plant were only barely inspected because they are still warranted by the construction company and the Water Cooperative did not want to lose the guarantee by opening them.

# 2. The Bolivian background

The Plurinational State of Bolivia, a land-locked state with no sea claims located in the mid-west of South America, between the Andes Mountains with the Altiplano in the west and the lowland plains of the Amazonian rainforest basin in the north, is a highly multicultural nation of approximately 11 million inhabitants, with 30 ethnolinguistic groups and 62 % of its inhabitants identifying themselves as indigenous (Economic and Social Council, 2007). The population of Bolivia has increased by more than three million within the last 20 years; by 2025 the United Nations estimates the number to reach more than 12.48 million (UNDESA, 2012).


*Figure 1 Map of Bolivia (US Army Corps of Engineers, 2004)*

Bolivia counts to the least developed Latin American countries (US Army Corps of Engineers, 2004). Even though the national poverty headcount ration dropped from 59 % to 39 % of the population in the period from 2004-2014, still half of the people lives in poverty declared by the World Bank (The World Bank, 2018). Around 40 % of Bolivians are poor (32 % were considered as indigent), which is high compared to the Latin American average of 25 % (US Army Corps of Engineers, 2004). 80 % of the population, both urban and rural, work within the informal sector and hence, Bolivia has the largest informal sector in Latin America (The World Bank Group, 2015a). The average life expectancy at birth is 68.7 years (United Nations Development Programm, 2016).

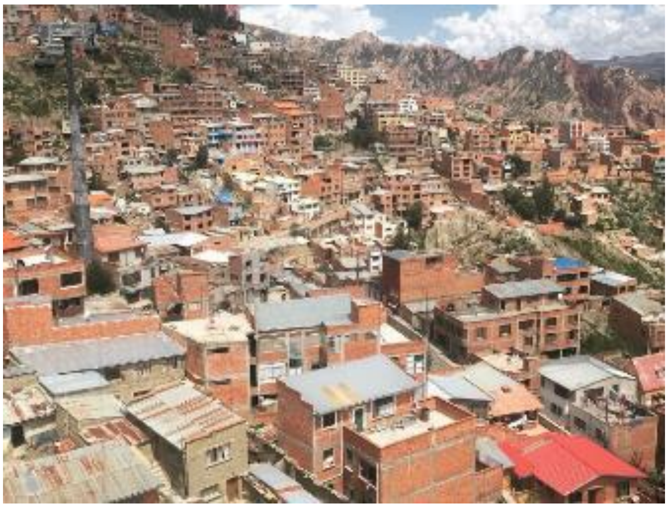


*Figure 2 Settlements in the South of La Paz March 2018 (Author's own copyright)*

The differences in living standards between urban and rural areas are significant. Rural poverty has directed to an increasing migration and subsequent Bolivia is undergoing a rapid urbanization in the bigger cities in Bolivia, e.g. El Alto, La Paz, Santa Cruz, and Cochabamba; more than 65% of Bolivians are living in urban areas, with a projection of 80 % by 2050 (The World Bank Group, 2015b; UNDESA, 2012). For instance, El Alto has grown from nothing during the past 30 years to a population around 600,000 (US Army Corps of Engineers, 2004). As a result, unplanned informal settlements, poor infrastructure, land degradation, pollution, and access to essential health facilities like sanitation and drinking water, are challenging these cities, and makes is difficult to keep up with the rapid population growth and to cover the needs of the Bolivian population (UNICEF, 2010).

38 % of the children under 5 suffer from undernourishment. Bolivia recorded one of the highest child mortality rate in Latin America caused mainly from diarrheal disease alone (US Army Corps of Engineers, 2004). According to the United Nations Development Program (2016), an investigation of the impacts to overall poverty has shown, that the most causal for poverty in Bolivia is the living standard (50.2 %), followed by health (27.9 %) and education (21.9 %). Developments in health, water and sanitation are understood as one of the crucial areas to make a direct influence upon the poverty of the Bolivian nation (US Army Corps of Engineers, 2004).

*Figure 3 Water collection point in Bolivia (i)*

Water service and proper sanitation is a serious issue and the access variates from one city to another. According to the US Army Corps of Engineers (2004), 55 % of the population had access to potable water and 41 % to sanitation in 1994. In comparison to the north European countries, 100 % of the population have access to water and between 99.2-99.3 % to sanitation (data from 2015, the World Bank). By supporting financially the local water companies by international cooperation programs and organizations, Bolivia has done a first accomplishment towards a meeting of the Millennium Development Goal by reaching the national potable water supply coverage of the population to 78.5 % in 2011 (UNICEF, 2017; US Army Corps of Engineers, 2004).

Every city has developed their own administration and management system for their water supply. Groundwater supplies most of the potable water, however, population growth and increased agriculture contribute to water scarcities and caused an overexploiting of the wells in La Paz and Cochabamba (US Army Corps of Engineers, 2004). Figure 4 shows the sources of potable water for the major cities in Bolivia. To cover the need for more water for supply and

(i) *Source: Photography by Stephan Bachenheimeri, Access on 17/9/2018 http://glacierhub.org/2017/03/23/world-bank-study-proposes-solutions-to-bolivias-water-crisis/*

irrigation in the next century, dams are planned all over the country, such as the Misicuni Dam for Cochabamba (US Army Corps of Engineers, 2004).

| City | Source, Surface Water Production ($m^3$/yr) | % | Source, Ground Water Production ($m^3$/yr) | % |
|---|---|---|---|---|
| La Paz, El Alto | 60,590,592 | 92 | 5,052,864 | 8 |
| Santa Cruz | | 0 | 47,571,738 | 100 |
| Cochabamba | 7,920,000 | 34.8 | 14,808,629 | 65.2 |
| Oruro | 1,072,044 | 13.7 | 6,768,903 | 86.3 |
| Potosi | 8,167,824 | 100 | | 0 |
| Sucre | 6,851,048 | 100 | | 0 |
| Tarija | 7,153,920 | 65.7 | 3,732,480 | 34.3 |
| Montero | | 0 | 2,371,714 | 100 |
| Trinidad | | 0 | 1,946,021 | 100 |
| Yacuiba | 788,400 | 22.8 | 2,672,114 | 77.2 |

Source: ANESAPA, June 2002

*Figure 4 (left) Sources of potable water for the major cities (US Army Corps of Engineers, 2004)*

Most of the cities have realized treatment systems in urban cities, however, as mentioned before, half of the population is living in rural areas where only 24 % have access to improved sanitation services, states the Ministry of Water and Environment (UNICEF, 2010). The development on sanitation lays significant behind the development on drinking water (UNICEF, 2010). Gaps are significant, in rural areas where only 72 % of the population is using improved sources of water, but only 32% is using improved sanitation systems (UNICEF, 2015). For instance, the potable water covers 100 % in El Alto, however, the sanitation service is only covered by 54 %.

As common for developing countries, stabilization lagoons for sewage treatment are used in Bolivia discharging treated water to the water bodies (US Army Corps of Engineers, 2004). But nevertheless, only 5 of 13 of the biggest cities own a system for wastewater treatment, and only 3 of them are working effectively without deficits (US Army Corps of Engineers, 2004). La Paz with 835,400 residents (data from 2010) (Borsdorf & Stadel Christoph, 2015) does not own a wastewater treatment system and the sewage is drained untreated into the Rio Choquezapu which is used for irrigation purposes and direct discharge by most of the population in the downstream areas again (US Army Corps of Engineers, 2004).

The lack of wastewater treatment and uncontrolled abuse of nations' waterways by industries and agriculture are large contributors to the pollution of the water. As stated from the US Army Corps of Engineers (2004), the growth in agricultural land use has led to elevated levels of pollution from pesticides and herbicides, and from processing harvest crops, faced by the valleys and plains of the country. In the Altiplano, mining and deforestation have a serious impact on the quality of water. Surface water bodies are facing highly problems with increasing salinization with heavy metals and increased loads of deposits downstream (Miller, Hudson-Edwards, Lechler, Preston, & Macklin, 2003).

*Figure 5 Gold mining activity in Tipunai river in Bolivia (Photography Yvon Maurice, 11th June 1991)*

Even with facing many challenges, Bolivia has made a significant development of drinking water supply on a national level in the century; First by social movement organizations opposing privatization known as the Water War of Cochabamba (2000-2005) where demonstrators called for the right for water all over the nation, the water sector has been made public again (Baer, 2015). And then by Evo Morales - a former coca-farmer and the first indigenous president in Latin America - and his rule, the fundamental human right to access to water and sanitation has been transferred in Bolivia (Baer, 2015). "Water is a human right and not a private business", stated Evo Morales at a public event in Trinidad, Bolivia (2010). When he took office in 2006, he stated his promise to move water policy away from a private to a public model (Baer, 2015), and strengthens citizen participation within the sector. Under Morales ambitious goals and his future work plan, Bolivia shall gain universal access to drinking water by 2020 and sanitation by 2025 (The World Bank Group, 2015a; UNICEF, 2017). The Morales government claims responsibility for creating 48,000 new potable water systems in communities with less than 2,000 residents, which will provide water to more than 635,000 people (UNICEF, 2015, 2017).

*Figure 6 Cochabamba water war anniversary 2010 (Photography Mona Caron, 2010)*

## 2.1 Stakeholders

During the study two different stakeholders were involved in the outcome of the project. Both groups assisted to gather information about the study area, to investigate the plant, and contributed to the decision making during the analysis.

### The Water Cooperative: *Cooperativa de Servicios Publicos 'Florida' Ltda*

Founded in August 1972, the Cooperativa de Servicios Publicos 'Florida' Ltda provides and administrates the water and sewage services in Samaipata. The Cooperative's mandate is to service those within the urban area of Samaipata, an area which is just being redefined by the current municipal administration as part of its 15-year municipal plan.

The Cooperative operates with the following structure: The Directorate, elected publicly by its members every two years, includes two committees with five members each: The Administrative Committee and the Vigilance Committee. The Administrative Committee has the responsibility to oversee the finances, make personnel and major decisions around expansion and service provision. The Vigilance Committee is mandated to supervise all work by the Administration Committee, with specific powers to review financial expenditures and address major complaints. The Cooperative includes five technicians (three are plumbers) working daily. Two technicians have knowledge about the instructions at the drinking water plant and one technician about the distribution system. During the study a change among some of the staff in the office has took place. The Cooperative has a weekly meeting to oversee and discuss the tasks. For working in the Cooperative every member is compensated with 100Bs (~ $US 15) a week.

*Figure 7 (left) Office of the Water Cooperative and Figure 8 (right) Weekly meeting of the Water Cooperative March 2018 (Author's own copyright)*

### The citizens' initiative: *Todos somos el Agua Viva de Samaipata*

The interest on the improvement of the water situation in the village has formed a citizen's initiative within the residents. The population of the city is highly motivated and showing a participation in the improvement of the current situation. During the study, they introduced ideas for additional treatment measures and invited potential non-governmental organizations to support Samaipata in future work. One of their main goal is to find more biological and sustainable alternative solutions in the treatment chain and the distribution system. The citizens' initiative objective aims to make results and work on the water system more transparent and accessible for all citizens.

## 2.2 Background Samaipata

Samaipata located at the middle of Bolivia has a subtropical pleasant climate and is settled at an altitude between 1,600 to 1,800 m.a.s.l. (see Figure 9). The municipality counts approximately 5,000 inhabitants and is 3 h away from the eastern low-land city Santa Cruz by car (population 2.1 million) (Coop- de Servicios Públicos FLORIDA Ltda., 2018). The local economy mainly consists of tourism, agriculture, and crafts. Situated right under the Pre-Incan archaeological site El Fuerte which includes the largest carved rock in the world and close by the town of Vallegrande (Che Guevara's 'trail'), the town Samaipata is known as one of the main tourist destination in Bolivia (Ho & Sotelo, 2018). The area counting to Samaipata is 1,871.18 ha big and has a perimeter of 17.13 km (Coop- de Servicios Públicos FLORIDA Ltda., 2018).


*Figure 9 Location of Samaipata in Bolivia (Ho & Sotelo, 2018)*

Samaipata is home for some 300 foreigners of all generations, hailing from around 33 different countries, something that gives the town a 'cosmopolitan' feeling. Evo Morales has been named the municipality as one of Bolivia's 32 'eco-municipality' in his recent 15 year planning process encouraging organic agriculture, sustainable tourism, and energy (Ho & Sotelo, 2018).

*Figure 10 View from the top of the mountain El Sauce overlooking Samaipata (Photography by Andrew Madereugene, 16th of March 2016)*

The dry season is recorded between June to November. Following Figure 11 gives the rain data collection from a private rainwater harvest station in Samaipata. Regarding the data, an average precipitation of 655 mm in the year 2017 has been caught (Franken M. 2018, personal conversation, 24th April).

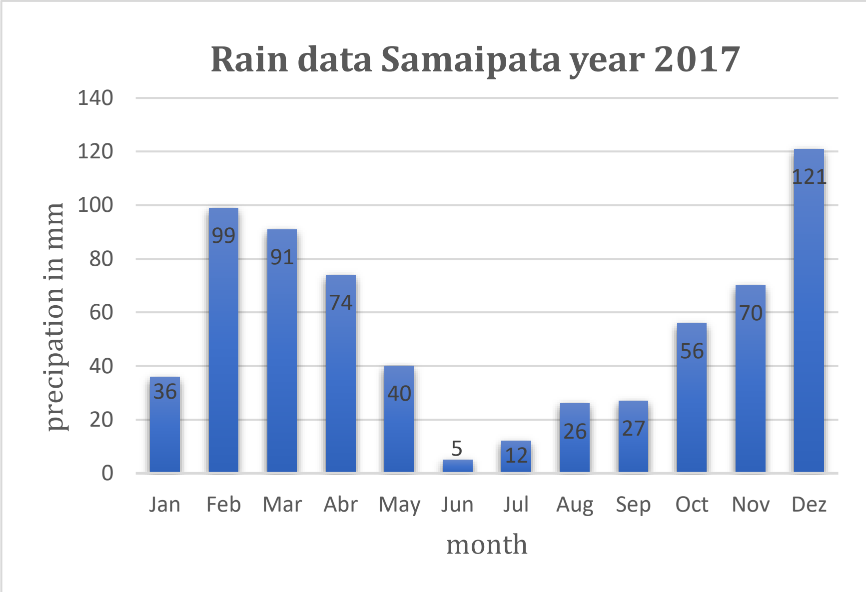



*Figure 11 Collected rain data in Samaipata of the year 2017*

## Population and water consumption

The Water Cooperative has registered a population of 4,935 inhabitants in 2017. They are assuming a growth rate of 0.06 % for the local permanent population and a growth rate of 7.3 % for the flux of tourists (Cardona Morón J. 2018, personal conversation, 4th May). In the year 2017, the Cooperative estimated that 54,271 tourists visited the town for an average of 4 days each, which results in a floating average population of 595 persons (Ho & Sotelo, 2018). The population projections for Samaipata, with an assumed exponential growth behavior, for 15-20 years, are illustrated in Table 1.

*Table 1 Population projections for Samaipata until 2030*

| Year | Permanent Population [Inh.] | Floating Population [Inh.] |
|---|---|---|
| **2017** | 4,935 | 595 |
| **2020** | 4,944 | 735 |
| **2025** | 4,959 | 1,046 |
| **2030** | 4,974 | 1,489 |
| **2035** | 4,989 | 2,119 |

According to data from the time period 1.1.2017 until the 31.1.2018, provided by the Water Cooperative, the total yearly water consumption was 326,186.84 $m^3$ in the year 2017. With 1,645 connections in the system and with 3.67 users per connection, the daily water consumption was 181.1 l/inh.*d. The Bolivian Norm NB 689 assumes a daily water consumption of 100 l/inh*d of a population in the range of 2,000-5,000 inhabitants (see Table 2).

*Table 2 Calculated data for daily water consumption in Samaipata*

| Data | Considerations | Daily water consumption [l/ inh.*d] |
|---|---|---|
| **NB 689** | Population of 2,000-5,000 inh. between 70-100 l | 100 |
| **Data Water Cooperative** | 1.1.2017-31.1.2018 (data from 13 months) | 181.1 |

According to The Engineers for Americas (2018), a peak-day factor with 2.22 times the daily average was calculated based on assumptions from the Water Cooperative that the total population doubles for a brief time creating a large water demand typically over the course of 4 days over peaks times over the year (e.g.: Christmas, New Year, Beginning of November, Carnival, etc.) (Ho & Sotelo, 2018).
The usage of water is distributed by 59 % domestic, 33 % commercial e.g. schools or hospitals, and 8 % are registered to be used by larger houses called 'fincas' with more than one kitchen (data year 2017).

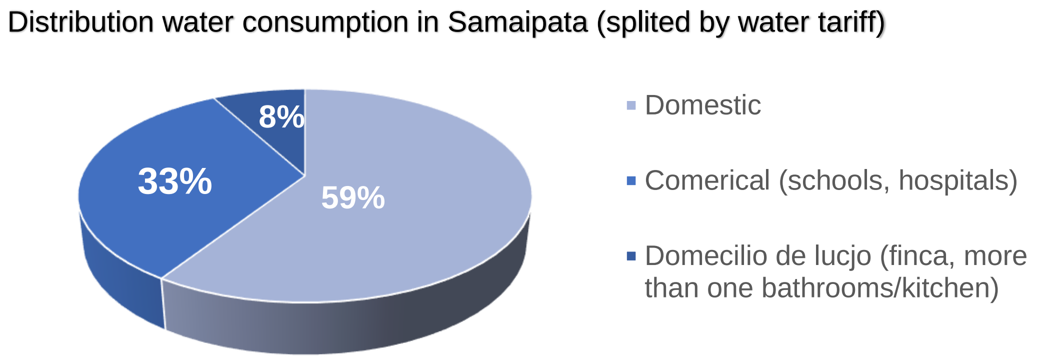



*Figure 12 Distribution water consumption in Samaipata 2017*

## The water system

The distribution system counts 1,645 connections with 1,247 residential connections and 247 commercial connections (Ho & Sotelo, 2018). Supply is given 24/7 and forced by gravity and pumps. The system consists of pipes of PVC and casted iron (FG). In all homes water measuring instruments are installed. However, 30 % of the distribution system is not receiving portable water (Coop- de Servicios Públicos FLORIDA Ltda., 2018).
The water system includes a wastewater system and a drinking water treatment plant. The treatment plant, which is designed for a flow of 15 l/s is in operation since July 2017.
Drinking water costs 2.5 Bolivianos per $m^3$ and sewage water costs 8 Bolivianos per $m^3$ per month. The Water Cooperative, 'Cooperativa de Servicios Públicos Florida Ltda.', is in charge of the whole water system (CASA, 2018).

The drinking water system is supplied by six sources: three water surface water catchments and three water wells, illustrated in Figure 13. The sources drain in different points in the system (see Figure 13). The supply from the surface water decreases during the time of the dry season (June to November). During this period wells are contributing to ensure enough water flow (Water Cooperative 2018, personal conversation, 8th April).
Currently, the Water Cooperative is also in the process of investigating and designing a new water supply source 'El Astillero'. This project joins three sources and includes a new water storage tank, which will connect to the existing distribution system, and additionally, to homes with a future extension of the system (Ho & Sotelo, 2018).

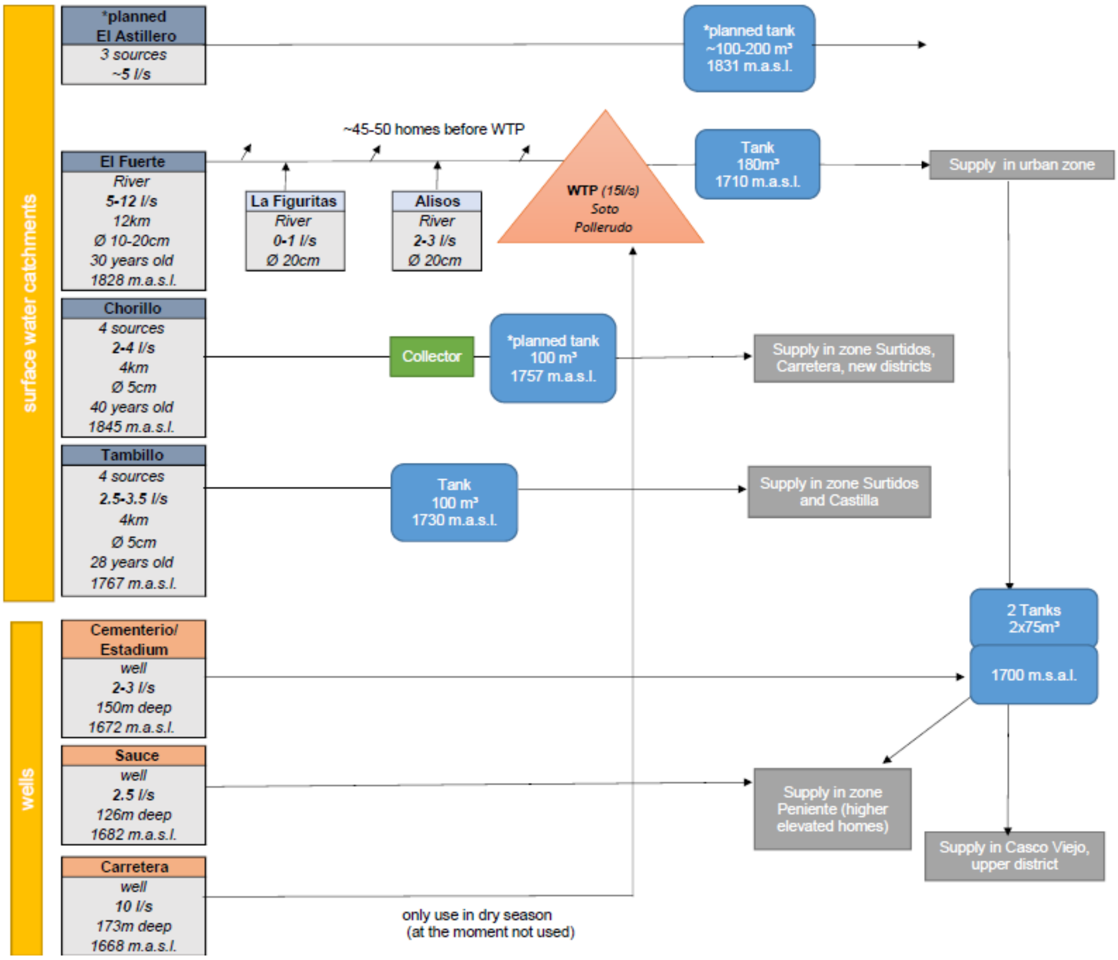



*Figure 13 The water distribution system and the sources*

The Chorillo intake offers additional sources, however, some of them where already shut down due to poor water quality after an investigation in 2017 (Ho & Sotelo, 2018). All wells are used as secondary sources only to support the supply in dry season. There is no storage tank between the wells and the districts above the wells. According to the Water Engineers of the America (2018) it is assumed that these areas will have private tanks (Ho & Sotelo, 2018).

The existing system can be operated as two separate systems (see Figure 14). The northeast sector (zone Surtidos and Castilla) is primarily served by the intake Tambillo. There exists a 5cm mainline isolation valve that essentially separates this sector from the rest of the central system. At the moment it is closed, but it can be opened in the case to drain water in either direction (Ho & Sotelo, 2018).

Between the intake of El Fuerte and the Water Treatment Plant exist 45-50 homes (Solar Sibaute J. 2018, personal conversation, 1st May). An investigation of the flows (9.4.2018) has shown that 15 l/s comes from the source El Fuerte, but only 10 l/s arrives at the treatment plant, which means that the houses before the plant consume already 1/3 from the water.

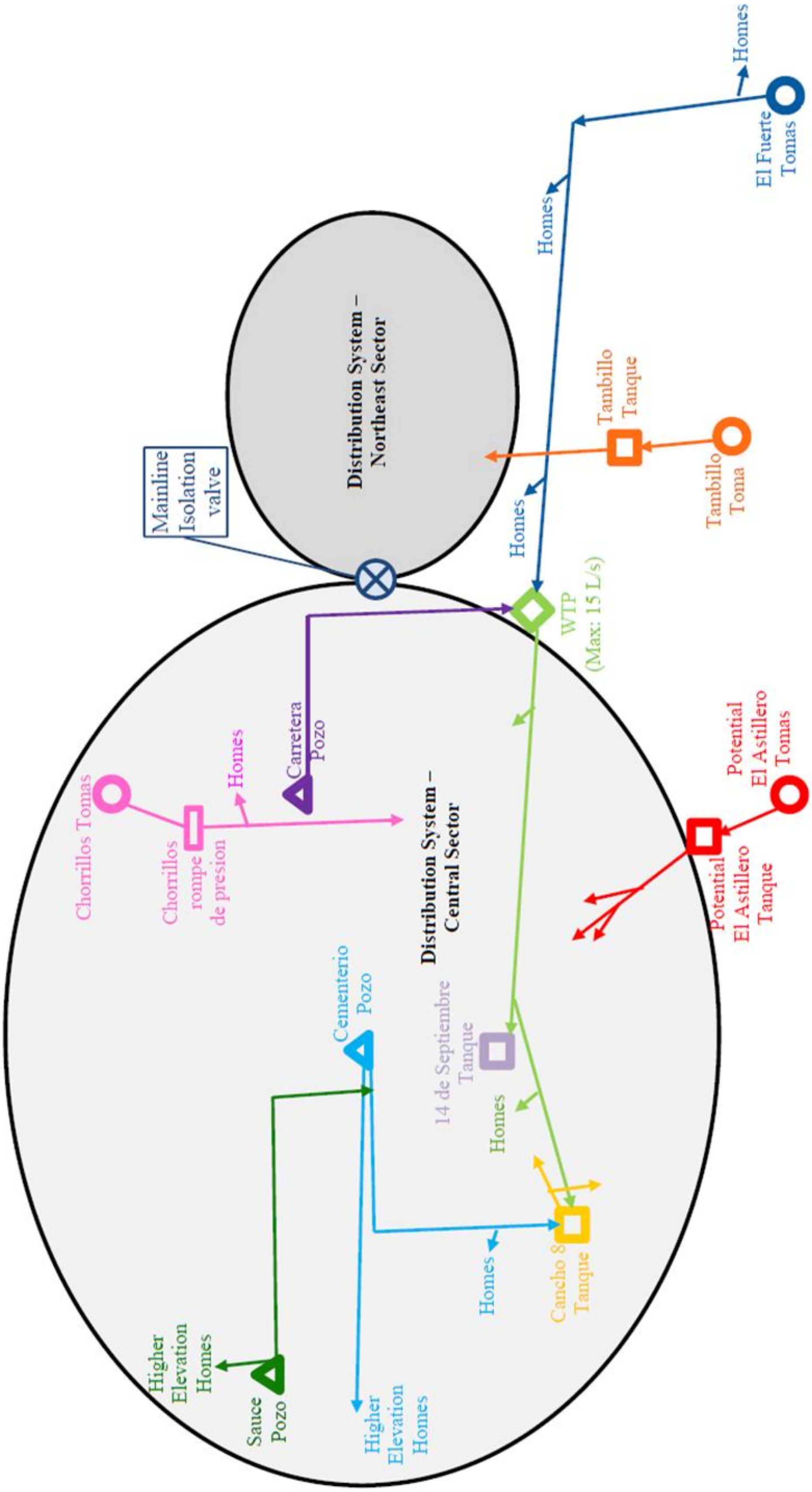



*Figure 14 Distribution system Samaipata (Ho & Sotelo, 2018)*

The source El Fuerte and the well La Carretera have been chosen to be treated in the plant, due to their poor water quality and because both are contributing each with approximately 30 % to the system (El Fuerte up to 15 l/s and La Carretera up to 10 l/s) (Water Cooperative 2018, personal conversation, 8th April). Other sources like Chorrillos or Tambillo have not been recommended to connect to the plant in regard to lower evaluation and pressure problems (Ho & Sotelo, 2018).


*Figure 15 Satellite picture of Samaipata, location of the intake of the sources, the distribution system (Google earth 28th January 2017, scale 1: 10.22 km) (Data provided by the Water Cooperative, 2018)*

| Color | Name of the source |
|---|---|
| | El Fuerte and La Carretera |
| | Tambillo |
| | Chorillo |
| | Pozo Sauce |
| | Distributed area by Tambillo |

*Figure 16 Legend to Figure 14: Name of the sources*

The Samaipata's system has four different existing concrete water storage tanks and two are proposed (El Asterillo and Chorillo). One planned storage tank of the Chorillos project will intersect the transmission line between the Chorillos intake and the distribution system. At the moment there is only a pressure break box in-between (Ho & Sotelo, 2018).

## Treatment of wastewater

The sewage system has been implemented since 1991 in a part of the town known as Casco Viejo (central zone of Samaipata). It's a typical wastewater treatment method in Bolivia: The wastewater is stored in four oxidation lagoons forced by gravity. Triggered by sunlight and complex microbial mechanisms, the biochemical oxygen demand (BOD), total suspended solids (TSS), and pathogens are reduced (Symonds et al., 2014). The lagoons are unlined and working at full capacity. The wastewater is discharging directly into the river and affects the downstream users. One of the goals of the Water Cooperative is to enhance the sewage water situation in future (Ho & Sotelo, 2018).


*Figure 17 (left) & Figure 18 (right) Oxidation pond of Samaipata August 2018 (Author's own copyright)*

## Treatment of drinking water

Through a partnership between the Governance (Santa Cruz state-level government), the Spanish-Bolivian non-governmental organization APEP (Asociacion Para la Eradicacion de la Probreza), the municipality Samaipata, and the Water Cooperative, the Sotopollerudo Water Treatment Plant (WTP) was built at the site of the pre-existing Sotopollerudo storage tank in 2017 (Ho & Sotelo, 2018). The plant takes water from the source El Fuerte and the well La Carretera. The well is only used in dry season, however, due to its poor water quality and problems in the past year (the pump felt in the well), it is not in use anymore (Water Cooperative 2018, personal conversation, 8th April). The sources are mixing directly in the flocculation tank in the plant. The plant is designed for a maximum flow of 15 l/s. La Carretera can contribute with a flow up to 10 l/s and El Fuerte between 5-15 l/s (Water Cooperative 2018, personal conversation, 8th April).

The following processes are existing at the plant:

1- *Pre-sedimentation:* A grid is installed before the intake of El Fuerte. Two more smaller rivers contribute in the system: Alisos 2-3 l/s and La Figurita 0-1 l/s.
2- *Deaeration:* A multi-step concrete splash structure before the plant is installed to remove nitrogen and ammonia from the water. During the time of investigation in this study, the structure was not in use.
3- *Coagulation, Flocculation, Sedimentation:* In the tank (two chamber basin) Aluminum Sulfate is injected to feed the water. The system does not have mixers and rely on gravity for floc removal. The accumulated residuals are drained in nature.
4- *Filtration:* Two Granular Sand filters in a row followed by an activated carbon filter are used for filtration. The first sand vessel has a coarser media than the second. The sand filters are back-washed in a 12 h interval, however, the design back-wash period was originally every 15 days. The activated carbon is operated at 1 bar, when the pressure reaches 2 bar, it is back flushed. Both filter systems are still authorized by the construction company. The technicians cannot open the filters without presence of the construction company.
5- *Disinfection:* A peristaltic pump injects sodium hypochlorite for bacteriological inactivation.
6- *Storage at the Sotopollerudo Tank:* The tank has a capture volume of 180 $m^3$.

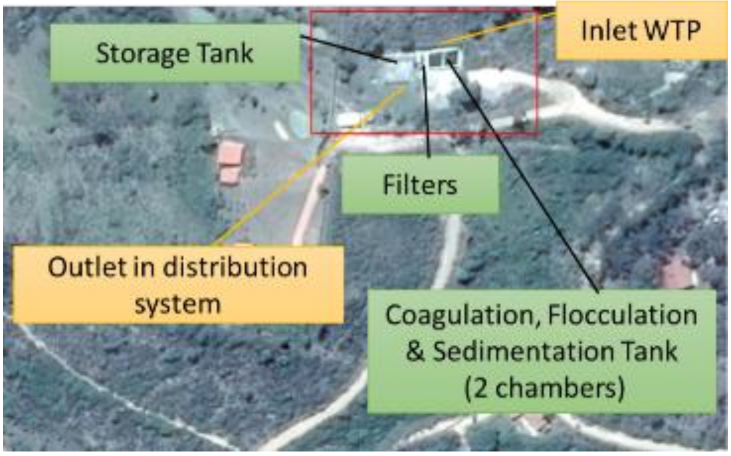



*Figure 19 Top view WTP and location of treatment steps (Google Earth, 19.9.2018, scale 1:20m) (Data provided by the Water Cooperative, 2018)*

Summarized in Table 3, the construction company mentioned the water composition as a significant base in the planning process of the treatment steps of the plant (S.R.L., 2016). In orange are highlighted the values exceeding the Bolivian standard in 2016. The water was only extracted from the surface water source El Fuerte and has shown increased values of turbidity and total iron before the plant was built.

*Table 3 Raw water composition before building the plant (2nd of November 2016)*

| Parameter | Unit | Analysis 02.11.2016 | NB 512 |
|---|---|---|---|
| **pH** | [-] | 7.5 | 6.5-9.0 |
| **TDS** | [mg/l] | 449 | 1,000 |
| **Conductivity** | [µS/cm] | 898 | 1,500 |
| **Turbidity** | [NTU] | 8.2 | 5 |
| **Total Iron** | [mg/l] | 0.48 | 0.3 |
| **Total Hardness** | [mg/l] | 275 | <500 soft water |
| **Total Alkalinity** | [mg/l] | 225 | 370 |
| **Temperature** | [°C] | 25.8 | / |


*Figure 20 Location of WTP (two red pipes La Carretera and El Fuerte mixing in the WTP, orange rectangle is the WTP) (Google earth (28th of January 2017), scale 1:3,77 km) (Data provided by the Water Cooperative, 2018)*

### Treatment in other parts of the distribution system

The other sources of Samaipata are not treated; not even by chlorination (Water Cooperative 2018, personal conversation, 8th April). Two chlorination test-unit systems have been installed to serve as test prior for the Water Cooperative`s decision making if they want to purchase these in future. In the time period, July to November 2017, a Gutwasser chlorination test- unit on the downstream side where the well Sauce connects to the discharge pipe of the well Cementerio was operated. Additionally, it was planned to install a Kobras test-unit downstream of the Chorillos intake and at the Tambillo tank. Both units use organic Trichloro tablets and do not require electricity to operate (Ho & Sotelo, 2018).

## 2.3 Problem description

At the beginning of the study the Water Cooperative and people from the citizen initiative asked for support of the municipality Samaipata in guidance of the water system and in operation the drinking water treatment plant.

These main problems were noted:

a. Residual chlorine is not reaching the end of the distribution system: Residents have measured the residual chlorine value of zero in their houses (see Appendix B Figure 73).

b. Controlling the water turbidity after the plant was built in summer 2017, is one of the main challenges. Especially, in wet season, the turbidity is highly flocculating. A water analysis of the effluent of the WTP has shown a turbidity of 1.0 NTU in dry season (30.10.2017) and a value of 11.12 NTU two months later in wet season (20.12.2017).

c. Residents have reported depositions of sediments in the sinks in their houses coming from the tap water. An investigation of CASA has referred that there is no visible reduction of turbidity within the treatment processes of the plant (CASA, 2018) (see Appendix b Figure 73 until and Figure 76).

d. Distribution system: Not all parts of Samaipata are supplied (see Appendix B Figure 77). and pressure problems in the system are noted (small air bubbles)

e. The water tastes poor when the well La Carretera is mixed to the plant. The Water Cooperative decided to shut down the well.

f. Since the building of the plant, the construction company did not respond to requests of the Water Cooperative. Several documents of the plant are still missing, which are essential to operate and maintain processes of the plant. The Water Cooperative has no authorization by the construction company to open facilities for instance the filters, they are still warranted.

g. Drinking water quality: The people are not taking water from the taps for cooking or drinking purposes because of the unstable properties of the water quality.

# 3. Theory

This chapter aims to theoretically present the technical terms that are of relevance to this thesis. Chapter 3.1 includes 1) an analysis of water treatment systems in developing countries in regard on the South American context, 2) explanations of the most common treatment techniques and 3) a summary of the economic aspects of these treatment technologies. Chapter 3.2 explains the two methods used in the health risk assessment.

## 3.1 Water treatment systems in developing countries

Water purification can be divided into a decentralized (point of use) and centralized scale treatment involving various deceives and techniques alone or in combination (Ali, 2010). In contrast to developed countries, economies are weaker, and infrastructure is not as developed. Even if water supply reached 69 % in rural areas in developing countries in 2000, only 34 % had access to piped sanitation (Johnston, Heijnen, & Wurzel, 2001). Often conventional drinking water treatments such as in developed countries are often unsuitable for these cases.

### 3.1.1 Centralized water treatment systems

Centralized water treatment plants are using coagulation, flocculation, and disinfection which are the most effective in treating large flows of water according to Kausley (2018). Centralized plants are reliant on treatment and distribution infrastructure and governmental funds, and thus mainly occurring in cities.

In the municipality Sacaba located 13 kilometers eastward from Cochabamba in Bolivia, a treatment chain of coagulation, flocculation, and disinfection is used to provide drinking water states the engineer of the plant (2018, $17^{th}$ May). Water is coming from a river and lagoons draining over aeration stairs in the flocculation gravity forced basin consisting of two parts (rapid mixing chamber and a slow mixing chamber). The coagulant poly aluminum chloride (PAC) (25 kg used for 3 days) is added at the inlet of the plant. Two sedimentation basins in a row separating the sludge from the water over an overflow installation and four rapid sand filters are followed. Finally, the water is disinfected with Trichloro in a 'GOOD AGUA' system and stored in two tanks. Turbidity is reduced in the treatment plant from 10-11 NTU to 2-3 NTU in the rainy season (personal conversation with the engineer of the plant of Sacaba, 2018 $17^{th}$ May)) .


*Figure 21 Flocculation basin in Sacaba (Author's own copyright) & Figure 22 'Good Agua' Disinfection system in Sacaba 2018 (Author's own copy right)*

### 3.1.2 Community and household treatment systems

For places where centralized networks do not reach yet, community (village level or group of households) and household treatment have high potential in development (Ali, 2010). A wide range of technology combinations have been proposed to improve the drinking water quality (Table 4). In communities, variations of systems with coagulation, flocculation, filtration, adsorption, ion exchange, electro-dialysis and reserve osmosis (RO) exist (Kausley, 2018). In comparison to centralized systems, the operation cost is higher, and they are mainly based on funds of the government or NGOs. However, initial costs and fixed costs are low. Often the system is located at a central location from where the community members can collect drinking water in storage containers (Ali, 2010).

Since water treatment plants are mainly inexistent in rural areas of the third world countries, household systems are options to treat water at the point of use (Bitton, 2014). One benefit is that the risk of contamination through water distribution will be avoided (Clasen, 2009). These inventions need to be simple, low cost and require locally available material. (Bitton, 2014). Implementing this system, it is assumed that people are skilled in the operation and the necessary maintenance (Kausley, 2018). The methods are based on chlorination, boiling, filtration, solar disinfection, flocculation in combination with chlorination (Bitton, 2014). According to Sobsey (2002), ceramic and bio sand filters showed the highest potential for sustained use by the consumers.

*Figure 23 SODIS promoted in Tiquipaya, Bolivia (ii)*

Solar drinking water disinfection systems (SODIS) is a disinfection method using heat and ultraviolet radiation are well-known as simple environmental, low-cost solutions for home treatment and safe storage (Christen et al., 2011). Clasen reported (2009) more than 2.1 million users at the end of 2007. The NGO Fundación Sodis widely encourages solar disinfection in seven Latin American states. Showing in labor studies that SODIS is highly effective in inactivating waterborne pathogens, 11 communities (200 households, 349 children) were trained for one year to put water-filled clear plastic bottles (1-2 l) into the sun on the top of their houses for at least 6h in rural areas of Bolivia (Mäusezahl, 2009). Christen et al. (2011) suggested SODIS as an initial implementation for drinking water treatment in low-income population which can be sustained in use over time (Christen et al., 2011). Table 4 gives an overview of implemented treatment technologies on community and household levels of collected case studies.

*(ii) Access at 5.10.2018, http://www.puntolatino.ch/ecologia/ecologia-notas-y-entrevistas/5764-ecologia-notas-escuelas-con-agua-segura-en-tiquipaya-bolivia-por-fabian-suter-y-elsa-sanchez*

*Table 4 Overview of treatment technologies on community or household levels established in 3rd world countries*

| Treatment | Examples on case studies located | Reference |
|---|---|---|
| **Biosand filters** | Rwanda, Columbia, India, Bali, Bangladesh, Cambodia, Guatemala, Kenya, Dominican Republic | Kausley 2018<br>Borovac, 2009<br>Dorea, 2011<br>CDC, 2003<br>Clark, et al. 2012<br>Bitton, 2014 |
| **Bank filtration** | Bolivia | Blavier et al., 2014 |
| **Water disinfecting hand pump** | India, South America | Kausley 2018 |
| **Electro-disinfection system** | Iraq | Esposto, 2009 |
| **Mixed-Oxidant Gases Generated on Demand Technology (Disinfection)** | Honduras | Thomas & Jay, 1998 |
| **Terafil community filter** | Odisha and Karnataka (India) | Kausley, 2018 |
| **Drinkwell system (tube for arsenic, fluoride, iron removal)** | India, Brazil, Chile, Bangladesh | Kausley 2018<br>Hall, 2012<br>Johnston, Heijnen, & Wurzel, 2001 |
| **Lifestraw community filter (ultrafiltration membranes)** | India | Kausley 2018 |
| **Water ATMs (ultrafiltration and osmosis)** | India | Kausley 2018 |
| **Solar water disinfection (SODIS)** | Nepal, Kenya, Bolivia, Brazil | Kausley 2018<br>Bitton, 2014<br>Vivar, et al., 2013<br>Mahon & Gill, 2018<br>Christen et al., 2011<br>Marques, et al. , 2013<br>Mäusezahl et al., 2009 |
| **Pur system (Coagulation, flocculation, disinfection)** | Bangladesh | Kausley 2018<br>SOUTER et al., 2003 |
| **Sono filter** | India | Kausley 2018 |
| **Flocculation-disinfection system** | Guatemamala | Reller et al., 2003<br>Chiller et al., 2006 |
| **Sono-3-Koshi filter** | Bangladesh | Kausley 2018 |
| **Ceramic water filters** | Colombia, Bolivia, Nigaragua, Cambobia, Zimbabwe, South Africa, | Kausley 2018<br>Bitton, 2014<br>Center for Disease Control and Prevention, 2003 |
| **Terafil household filers** | Asia | Kausley 2018 |
| **Sujal filtration filter** | Asia | Kausley 2018 |
| **Tata Swatch filtration system** | India | Kausley 2018 |
| **Good agua system (disinfection)** | Bolivia | Kausley 2018 |
| **WaterGuard™ sytem (disinfection)** | Kenya, Haiti, Indonesia, Peru, Eucador | CDC, 2013<br>CDC & CCHI, 2001 |

### 3.1.3 Portable treatment systems

Different mobile water systems are designed as small units and can be carried to treat water at the water source as treatment systems (see Table 5). Often, they are used in emergency cases after natural disasters because of their easy transport and distribution. In developing countries, NGOs are using disinfectant tablets in communities due to their low costs. Chlorine tablets can treat water in between 5 to 10 min (Kausley, 2018).

*Table 5 Overview of portable treatment systems in 3rd world countries*

| Treatment | Examples of countries in use | Reference |
|---|---|---|
| **Water purification tablets (NaDCC) (disinfection)** | Bangladesh, Zambia, Madagascar, Ghana | Bitton. 2014<br>Clasen, 2009 |
| **Bottle purifiers** | South Asia and Latin America | Kausley 2018 |
| **Steripen, Lifestraw, Shudh Pen (Treatment pen)** | South Asia and Latin America | Kausley 2018 |
| **Emergency batch water treatment (potable filtration basin)** | Pakistan | Dorea, 2011 |
| **Emergency filter Oxfam field Up-flow 'Clarifier'** | Indonesia | Dorea, 2011 |
| **P&G system<br>(flocculation/ disinfection powder)** | Haiti, Kenya | Center for Disease Control and Prevention, 2003<br>CDC & CCHI, 2001 |
| **Membrane filtration** | Dominican Republic, Ecuador | Groendijk, et al. , 2009<br>Arnal, et al. 2007 |

## 3.2 Treatment Technologies

### 3.2.1 Thermal (heat) technologies

Boiling and pasteurization typically higher than 63 °C for 30 min are heat-based technologies. (WHO, 2011). Boiling is effective in destroying all kind of waterborne pathogens and can be applied to all waters, including those with high turbidity of dissolved constituents. According to Bitton G. (2004) studies in developing countries have shown that boiled water had led to 86 % mean reduction of total thermotolerant coliforms in a rural area in Guatemala. In Cambodia, a similar study has led to 98.5 % inactivation of Escherichia coli in water samples (Bitton, 2014). Even if a treatment plant is available residents in Latin America do not trust in the quality of water supply and therefore also boil tap water before drinking (Thomas & Burch, 1998). In Cochabamba, in Bolivia additionally cooking of tap water is used to ensure safe consumption (Z. Veizaga, personal conversation 17th April 2018). Sobsey states (2002) that one major disadvantage is the energy consumption regarding the availability and cost of fuel. To provide a daily quantity of drinking water (10 l) three times the amount of fuel to cook a daily meal is needed (Bitton, 2014).

## 3.2.2 Aeration

Aeration oxidizes and precipitate ion, manganese and sulfur, volatile organic compounds and some taste and odor compounds (Sobsey, 2002). High-performance aeration is applied for the removal of radon in groundwater supplies and can achieve up to 99.9 % removal (WHO, 2011). Four different types of aerators are usually used: gravity aerators, spray aerators, diffusers and mechanical aerators (Shammas & Wang, 2016b). According to Sobsey (2002), the technical difficulty in use by locals is low and the costs for a household level are less than $ 10. Aeration is a common used method in a conventional treatment chain in Latin America, due to the country's problems with high arsenic content (Litter, Morgada, & Bundschuh, 2010).


*Figure 24 (left) Oxidation in a WTP in Bolivia (CASA, 2017) & Figure 25 (right) Aerator in Bolivia (CASA,2017)*

## 3.2.3 Rapid sand filtration (RSF)

Silica sand and anthracite coal used alone or in multi-media combination are the most common types of granular media bed filters. More layers in filters have been shown to function more efficient in the use of the whole bed depth for particle retention and can be operated at higher flow rates (WHO, 2011). Porosity is formed by the grain size. The grain size distribution has important impacts on particle removal, head loss, and backwashing requirements for media filter (American Water Works Association, 2011). Tanks (<100 $m^2$) are mostly open rectangular designed and generated at a 4-20 $m^3/m^2$*h flow rate. The purified water is collected via nozzles at the bottom of the tank and solids are removed by backwashing with treated water (WHO, 2011). Effective backwashing is essential for long-term service to eliminate solids, to clean the media and to avoid problems of mudballs and filter cracks (American Water Works Association, 2011). Pressurized filters in mostly cylindrical shell treat up to 15 $m^3$/h. This kind of filters is necessary when the water head needs to remain in order to avoid the need for pumping (WHO, 2011).
Filter material granular activated carbon (GAC) can replace parts of the sand proportion in rapid sand filters. GAC filters are often considered in cases where a removal of biodegradable organic matter (BOM) is desired. GAC filter perform better in challenging environments of lower temperature and oxidants in backwash water (Shammas & Wang, 2016 b).
In India the construction of a small and medium sized RSF has shown that the initial expenses for the construction were high, however, operation and maintenance costs are in comparison to other types of treatment (Visscher, 1990).

*Figure 26 Sand filter in the WTP in Santa Clara in Cuba 2015 (Author's own copy right)*

### 3.2.4 Slow sand filtration (SSF)

Elliott, et al. (2008) estimates that over 500,000 people in developing countries are using slow-sand filters. In Nicaragua, for instance, the technology is often used on a household scale as Biosand filtration (BSF) (Borovac, 2009). Sand filtration separates water from suspended organic material, inorganic material and can eliminate 99 % of bacteria. Some are even able to remove viruses (Clark et al., 2012).
Two mechanisms are used during the process: the mechanical filtration of bacteria through the grains of sand, and the adsorption of bacteria to the top of a biofilm layer know as 'schmutzdecke' (CAWST n.d; Dow Baker et al. 2008). A fine sand has a size of roughly 60 micrometers. The distance between the particles very fine sand can even be less. When water passes through bacteria are trapped within the spaces between the sand and contribute to a biofilm. Initial filtration efficiency without a schmutzdecke layer is roughly 60 % (Clark et al., 2012). The biological processes that occur in the top layers of the filter include predation, scavenging, natural death/inactivation and metabolic breakdown states Clark (2012).
For effective working of the filters gathered particles need to be removed. A cleaned filter will need time to regenerate the 'schmutzdecke' that is why it is recommended to place multiple filters in a row. It should be noted that filtration techniques require raw water to have a turbidity less than 5NTU or prefiltered (sedimentation or roughing filtration), otherwise the system will require more often maintenance and cleaning to avoid pore clogging (Parrot, Ross & Woodard 1996) (WHO, 2009).
Clark (2012) recommends installing an activated carbon filter after a slow sand filter to remove the last organic particles and prevent of the reaction of chlorine from disinfection with organic materials to trihalomethane (THM). One advantage of this technology is that it can be built with locally sourced materials (Borovac, 2009). Other benefits are low operation, less maintenance requirements (sand scraping, replacement and cleaning) and long-term design of life. For household water filters the effective lifespan is estimated over 10 years. In Haiti filter still in use after 12 years showed an average 92 % removal of E. coli in studies (CDC, 2003).

### 3.2.5 Membrane processes

In South America, the use of membrane filtration has established in the treatment of surface water, especially to the issue of arsenic contamination (Maeng, Choi, & Dockko, 2015). Membranes serve as a barrier to prevent mass movement for solid, liquid and gas phase separation. Pressure is the driving force to transport the fluid across the membranes (American Water Works Association, 2011). Transmembrane pressure, flow velocity, water temperature, feed stream characteristics, and the membrane module characteristic are taking influence on the process (Shammas & Wang, 2016b).

A successful installed UF technology in a rural area of Ecuador (>500 inhabitants) has shown that this technology is easy to install, is compact, and works with a constant production, however maintenance and replacement costs are high and electricity is needed (Figure 27) (Arnal, et al. 2007).
Often membranes have problems with clogging when material is trapped in the membrane or on the surface (Kausley, 2018). Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO) are different kinds of membrane filtration (Shammas & Wang, 2016b). These types correspond to a decreasing pore size, and thus increasing transmembrane pressures, and decreasing recoveries (American Water Works Association, 2011). For example, in Switzerland, the LifeStraw Family, a gravity-based ultrafiltration device was conceived which runs without power to use in households. First prefiltration of 80 um separates coarse material, then water runs through a 1 m plastic pipe through the 20 nm membrane pore size with up to 12-15 l/h (Bitton, 2014). Clasen (2009) states that the filter achieved a log removal of 6.9 for E. coli and 3.6 for Cryptosporidium.


*Figure 27 (left) UF membrane in use in Ecuador (Arnal, 2007) & Figure 28 (right) MF in use in Bolivia (CASA, 2017)*

### 3.2.6 Disinfection

Chlorine is applied as a disinfectant in developing countries, next to bromine and iodine (Kausley, 2014). Chlorine breaks the cell membrane of a pathogen, interrupt the transmission way of food to energy and inhibits the reproduction (Drinan, 2001). In emergency cases, it was found as the most effective disinfectant because it can inactive high concentration of pathogens in a short time. Additionally, chlorine is used to prevent regrowth and recontamination of the system. A dose of 0.25 mg/l free residual chlorine is recommended for a TOC value of <25 mg/l. One side effect of using chlorine is the potential of the formation of chlorine by-products with organic compounds such as trihalomethanes (THMs) and halo acetic acids (HAAs). Aeration or activated carbon adsorption is used to remove natural organic material (NOM) in a previous step in the treatment chain in these cases (Drinan, 2001).

*Figure 29 Inlet of disinfectant in the pipe of a WTP in Bolivia (CASA, 2017)*

### 3.2.7 Chemical coagulation-flocculation and sedimentation

Microbes and other colloidal particles can be physically removed by chemical coagulation-flocculation and sedimentation (WHO, 2002). When water is pumped into a large settling tank, particles which have a higher density than water will settle down to the bottom by gravitational action (sedimentation or clarification) (Drinan, 2001). Very small particles (like colloids, bacteria, color particles, and turbidity) will not sink out of suspension under a prescribed time without the help of coagulants aids. Metal coagulants based on iron or aluminum are used commonly for community treatment (WHO, 2002). Rapidly mixing of the coagulants with water, and subsequent slowly and gently stirring before sedimentation will additionally enhance the formation of flocs (Drinan, 2001). Coagulation and flocculation neutralize the repellent negative charge that keeps particles separated and in suspension in water. WHO (2002) states that coagulation and the maximum reduction of pathogens can only be achieved when the coagulant dose, pH and mixing condition are controlled. Under optimal conditions, a microbial reduction of >90 to >99 % for all classes of waterborne pathogens can be reached. Bitton (2014) accounts that a well-working removal of turbidity and color will proceed to a more efficient disinfection and make the water more aesthetically pleasing.

*The Jar test - a tool for coagulation control*

Universally recognized as the most valuable tool for coagulation control, the Jar test optimizes the plant operations and is applicated as a design criteria for new plants or for plant expansion (American Water Works Association, 2011). The test is used for the coagulant selection, the coagulant dosage determination, the determination of the optimum aid selection, and for the optimization of mixing energy and time for rapid and slow mixing (MWH, 2012).

## 3.3 Economical aspects of treatment methods

Considering the diverse socio-economic constraints in developing counties treatment technologies need to be efficient, cost effective and user-friendly (Kausley, 2018). Table 6 is illustrating a summary of technologies mentioned in this thesis.

*Table 6 Overview costs, effectiveness and technical difficulty of technologies used in developing countries (labor costs are not included) (Thomas & Burch (1998), Sobsey, (2002), WHO (2011))*

| Technologies | Production [l/day] | Investment costs [$] | Operation costs [cents/m³] | Effectiveness | Technical difficulty |
|---|---|---|---|---|---|
| **Chlorine dosing at the plant** | 24,000 | 2,400 | 6 | *** | ** |
| **MOGGOD (24/7 supply)** | 24,000 | 48,222 | 73 | *** | *** |
| **Rapid sand filter** | 24,000 | 960 | 1 | * | * |
| **Slow sand filter** | 24,000 | 1,200 | 2 | ** | * |
| **Household filter** | 60 | 20 | 85 | ** | * |
| **Water boiling, purchased fuel** | 20 | 0 | 2,083 | ** | * |
| **Batch solar/ Sun tube** | 19 | 143 | 338 | ** | * |
| **Flow-through solar/trough** | 1,436 | 5,872 | 174 | ** | * |
| **Coagulation + flocculation** | Varies | Varies | Varies | Varies | ** |
| **Coagulation + flocculation + filtration+ chemical disinfection** | High | High | High to moderate | *** | *** |
| **Plain Sedimentation** | Varies | Low | Low | * | * |
| **Ozonation** | High | High | High | *** | *** |
| **Ion exchange** | High | High | High | */** | **/*** |
| **Aeration** | Varies | Low | Low | * | * |
| **UV lamps** | Low | Low | Low | *** | */** |
| **Membrane treatment** | Varies | Varies | Moderate | *** | ** |

- *Effectiveness in reduction of bacteria, viruses and protoza: *moderate **good ***excellent*
- *Technical difficulty: *low **moderate ***high*

## 3.4 Health Risk Assessment

In this study following approaches used to assess the annually infection rate of the pathogen load are explained.

### 3.4.1 Microbial Barrier Analysis (MBA)

Microbial Barrier Analysis (MBA) is a method to access the hygienic barriers in a water utility system. MBA is an adapted model to Good Disinfection Practices (GDP) and is a Norwegian method applied also in Sweden. The tool accesses the water safety of a current or proposed drinking water system in six steps based on water quality as well as combined treatment methods (Ødegaard, 2014). As last step the total provided protection (sum of log-credits) is compared to the recommended barrier height needed. If the provided protection of the technologies exceeds the recommended the removal rate, the treatment is sufficient (Ødegaard, 2014).

### 3.4.2 Quantitative Microbial Risk Assessment (QMRA)

The quantitative microbial risk assessment is a tool to ensure a certain drinking water quality by calculating the efficiency of the treatment plant in terms of reduction of microbial pathogens and final risk to consumers (Bichai and Smeets, 2013). Therefore, the Swedish QMRA tool (software) is used to calculate and quantify the health risk. The QMRA offers a platform to change input data of the water system and directly see the effect on the log reduction of the pathogens through the various treatment steps. This makes it possible to identify the weak points in the system and to apply required actions (Bichai and Smeets, 2013). A treatment plant should guarantee a sufficient removal of pathogens by multiple barrier principles, even under higher unexpected concentrations or a failing process in the plant. According to Hunter & Fewtrell (2001) the infectionrate should be less than 1 person per 10,000 persons per year.

# 4. Methodology

The project included two parts: The first part performed at the Sotopollerudo water treatment plant in Bolivia in the period April to June 2018. The analytical work of the water sampling and laboratory tests have been performed in the Centro of Agua y Sanemiento Ambiental (CASA) at the Universidad Mayor de San Simon in Cochabamba. The health risk assessment, evaluation of results and recommendations for improvements for the Water Cooperative were completed in a second phase in Sweden.

## 4.1 The selected system for this study

The initial step was to boundary the field of research in one part of the water system. The study focused on the drinking water supply chain coming from the treatment plant draining into the network of Samaipata including catchment areas, transmission lines, and the storage tank. In Figure 30, the investigated steps are illustrated. The chemical and physical treatment units have been examined. The first process in the plant (coagulation, flocculation, and sedimentation) and the last (disinfection) have been studied precisely, however, the access to examine the filtration process was limited.

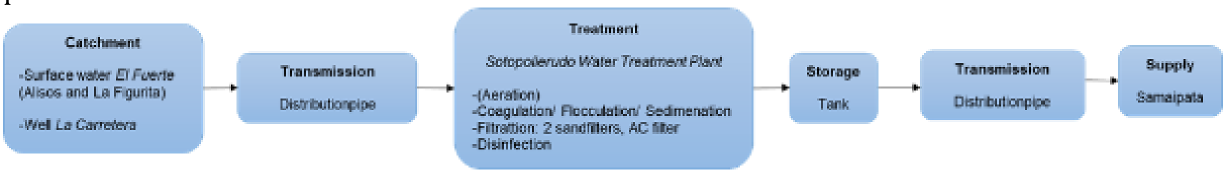



*Figure 30 System of investigation (*Aeration was not in use, thus not evaluated during this study.)*

### Previous studies

The approaches for the project were primarily formed on a visit of the Centro of Auga y Sanemiento Ambiental (CASA) three weeks before the start of this study in March 2018.

## 4.2 Methods

To fulfill the goal to evaluate the selected study area in terms of performance, design, operation, and maintenance several steps were set up to structure the work (see Figure 31).

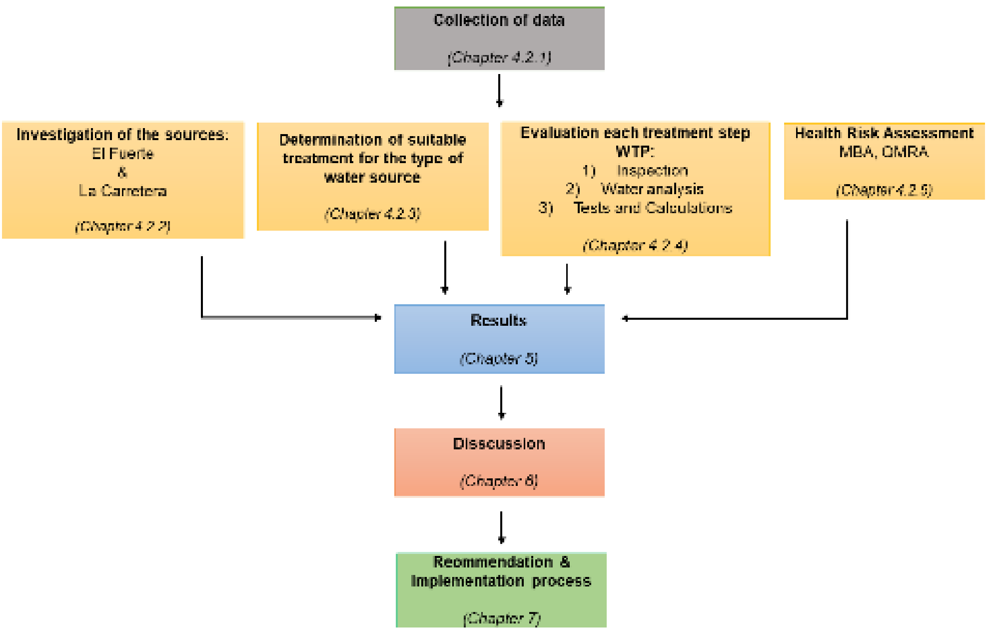



*Figure 31 Schematic outline of the project methods*

### 4.2.1 Information collection of the design of the plant

The information has been mainly gathered by personal conversations with members of the Water Cooperative, the two technicians, and several residents of the village. During the stays in Samaipata, the weekly meetings of the Water Cooperative have been attended.
In the first visit in Samaipata, all material from the office has been listed to gain an overview, what is still missing from the construction company and what material is available for the Cooperative to work with. The objective was to understand the design criterions for the treatment processes of the plant and how the plant is equipped. The available data was compared to categories referring to two guidelines of the German *Technical and Scientific Association for Gas and Water* (DVGW). The papers DVGW W1000/W1010 and VDI/ DVGW 6023 describe requirements for the qualification and organization of drinking water plants and suppliers.

### 4.2.2 Investigation of the sources El Fuerte and La Carretera

Both sources have been visited and assessed by a protocol for sanitary facilities for rivers and wells from CASA based on a guidance from UNICEF from 2009. The protocol questioned several sections of a water intake system (A to E) with the answer of Yes or No (see Table 7). The risk of contamination is judged by counting the amount of No answers and comparing this number to a legend at the end of the survey. There are given four categories categorizing the risk of contamination: Very high, high, low and very low. The protocols can be found in Appendix C.

*Table 7 Assessment sections during inspection of the well and the river*

| Category | River | Well |
|---|---|---|
| **A** | Surrounding and first impression | Circumstance well |
| **B** | Inlet point of intake | Transmission line well to tank |
| **C** | Reservoir in front of the intake | Tank |
| **D** | Outlet of intake | Distribution system |
| **E** | Distribution from the source to the WTP | Supply/ Others |

Only the first part of the intake of El Fuerte has been investigated during a hike under difficult circumstances. The upper part of the intake was not possible to access. Additionally, the conditions of the pipes were investigated.

The flow from the sources was measured with a bucket and a watch three times and the average was calculated. The flow from El Fuerte was determined at the outlet of the lower reservoir on the 8th of April 2018 in the morning and from La Carretera direct at the outlet of the well on the 2nd of May 2018 in the afternoon.

Information about the catchment areas and environmental influences were collected by interviewing the responsible technician, the president of the cooperative and citizens which are working with the livestock in the mountains.

*Figure 32 (left) & Figure 33 (right) Flow determination El Fuerte 8th of April 2018 (Authors own copyright)*

### 4.2.3 Determination of suitable treatment for the type of water source

In order to evaluate the appropriateness of the WTP samples from both sources were taken and analyzed in the laboratory of CASA in Cochabamba. The waters were studied in a wider field of physical-chemical parameters depending on the characteristic of origin (surface water or groundwater) and total coliform and E. coli as microbiological quality indicators.
The quality of El Fuerte has been analyzed twice: In the first analysis (9th of April/ in the change of wet to dry season) the choice of parameters was based on a water analysis before the plant was built (2nd Nov 2016: turbidity 8.2 NTU and Iron 0.48 mg/l) (S.R.L., 2016). The pH, permanganate Index and conductivity of the raw water were performed on the assumption that there are problems in the flocculation/sedimentation process (CASA, 2018), and thus to compare to the reduction process of the treatment plant. However, the gained data seemed not enough that is why a second sample (2nd of May/ dry season) was taken with a wider spectrum (Appendix C Table 40). In the Appendix C, a sampling protocol and the methods are given (Table 42 and Table 43). After collecting, the samples were sent with a bus to the laboratory in Cochabamba, (approximately 260 km) over an old route with a traveling time over 13 h on a non-raining day. For the microbiological analysis, a time frame of 30 h was given from sampling to reach the laboratory.

### 4.2.4 Evaluation of each treatment process in the treatment plant

To analyze each treatment step, (1) the plant was inspected, (2) water samples were taken at seven points in the plant and (3) tests and calculations have been done. The focus of the study was defined on the coagulation, flocculation and sedimentation tank (CFS tank).

1) Inspection

All parts of the treatment plant have been inspected. It has been assessed if all facilities are built and operated as described in the collected papers from the office.

2) Water Sampling

Samples from seven locations were taken before and after each treatment step in the plant (see Figure 35). In a first sampling only a few parameters were measured considering the problem description from the Cooperative and the citizens. In a second sampling, some parts were studied more in detail. On the 9th of April 2018, at seven places were sampled. On the 2nd of May, a sample of the total effluent (P5) was repeated due to the lack of clarity of the value of pH and the Permanganate Index. Additionally, it was decided to choose a larger spectrum for this analysis. The analysis at the end of the distribution system (P7) was also taken a second time at a different tap because the water at the sampling point was mixed with water of other sources. Thus, a house was chosen 1-2 km after the plant which has only supply from the WTP (see Figure 34).

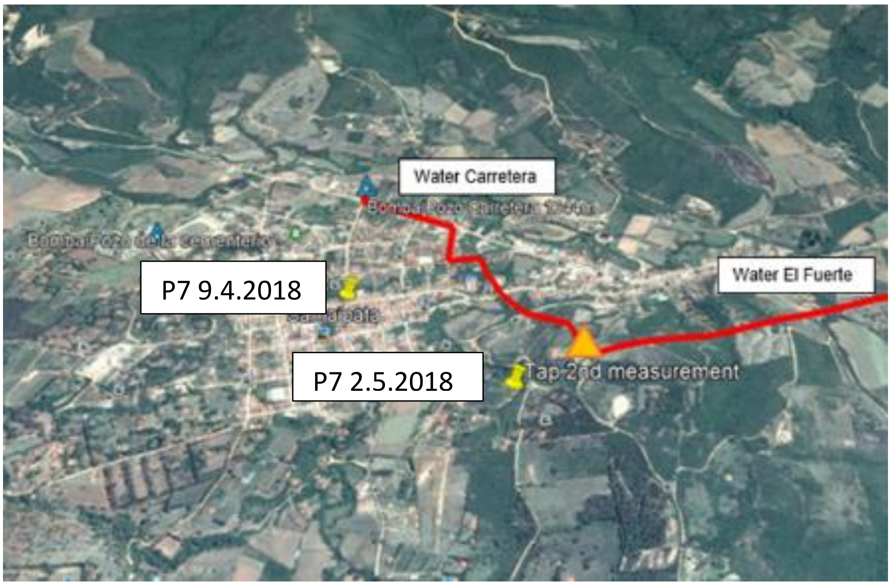



*Figure 34 The yellow pins are the locations of sampling of P7. The two red pipes are La Carretera and El Fuerte mixing in the WTP. The orange triangle is the location of the WTP (Data provided by the Water Cooperative, 2018)*

In the inlet and outlet of the WTP, the microbiological indicator total coliform and E. coli were examined to evaluate the removal of pathogens (P1 and P5). Furthermore, due to high values in the analysis of 2016 (Table 3), the removal of magnesium and iron was studied at this locations as well. To analyze the concern about the treatment of turbidity, the elimination of particles was analyzed, and turbidity, conductivity, and pH were investigated in the system. In addition, at the points P1, P2, P5 and P6, the Permanganate Index was analyzed in order to obtain information about the value of the natural organic material, which can give information about the particles as well as about the formation of by-products during chlorination due to the statement of inhabitants that no residual chlorine is reaching the end of the system (see Appendix C Table 41). In Appendix C, a sampling protocol (Table 42) and the methods are given (

Table 43).

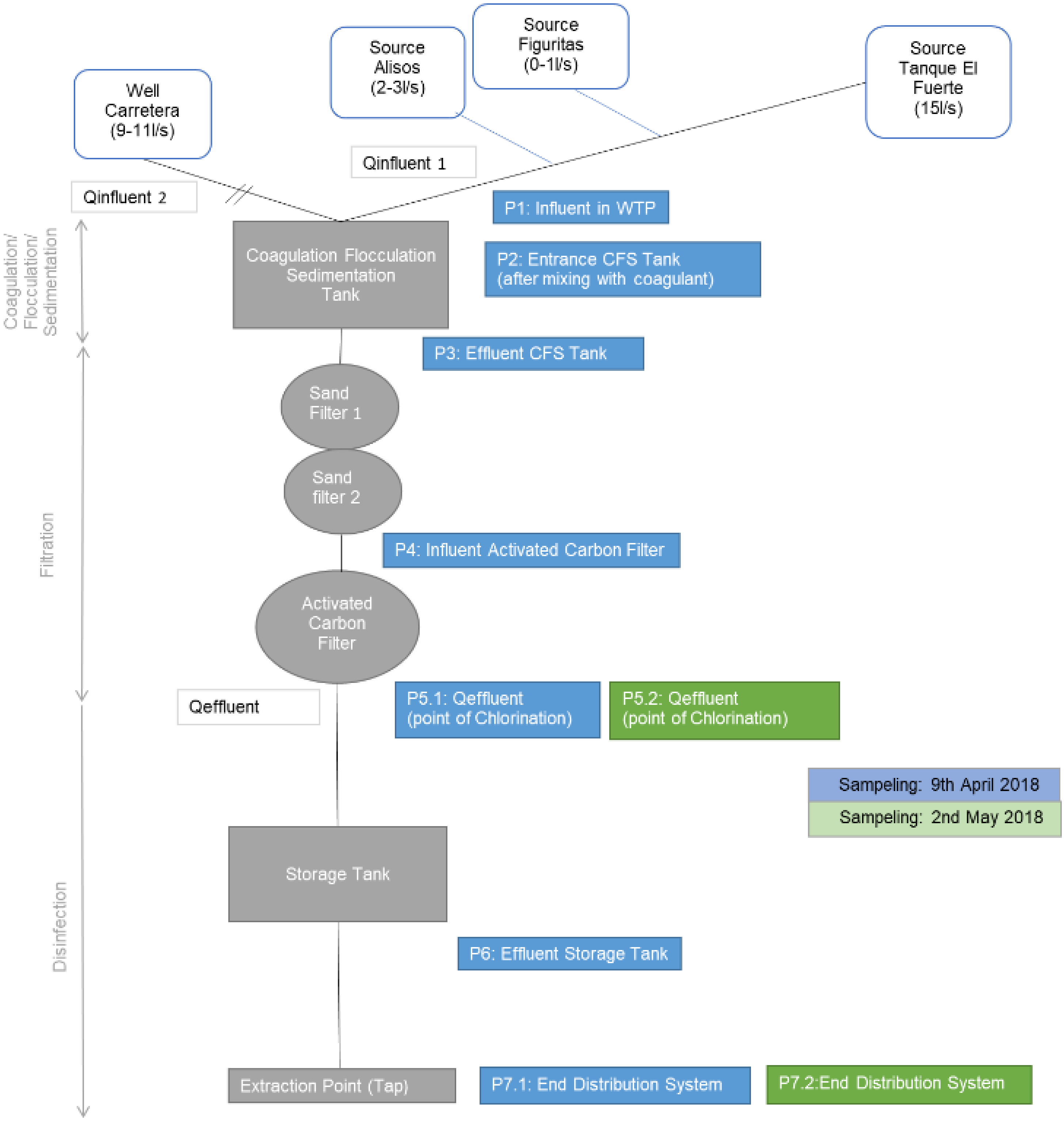



*Figure 35 Points of sampling at the water treatment plant of Samaipata 9th April and 2nd May 2018*

3) Test and calculations:

Following checks have been performed to evaluate the water treatment plant at:

*Coagulation, Filtration and Sedimentation Tank*

*Table 8 Overview performed tests at the CFS Tank*

| Tests and Calculations |
|---|
| ✓ Measurement of the flow into the plant<br>✓ Investigation of the flocs<br>✓ Investigation of the sludge at the bottom of the CFS tank<br>✓ Calculation of the retention time<br>✓ Inspection of the cleaning process of the tank<br>✓ Inspection of the mixing of the aluminum sulfate of the technician<br>✓ Recalculation of actual dosage of aluminum sulfate<br>✓ Jar test: Determination of the optimal dosage<br>✓ Operation of the optimal dosage at the plant<br>✓ In buckets at the treatment plant<br>✓ In the CFS tank |

The flow into the plant was measured with a bucket (volume = 18 l) and a watch three times and the average was calculated on the 9th of April 2018 (see Chapter Results 5.2.1). The value has been compared to the measured inflow from El Fuerte to determine the water losses from source to plant (Appendix C Figure 90).

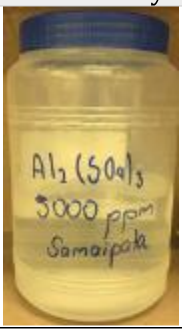
Due to the fact that most of the information of the plant was collected by conversations of the technicians and that some statements differed from one to the other worker, these statements have been verified by attending the technician's routine at the plant. Therefore, the cleaning procedure of the CFS and mixing procedure of the coagulant was accompanied (Appendix C Figure 90 and 91).

The floc formation has been observed by taking a sample in a depth of 0.5 m from the surface in the beginning and close to the outlet of the CFS tank. Additionally, during the cleaning process, the agglomerations on the bottom have been investigated to get more information about the amount of sludge, the appearance of sludge and the place where it is settling in the tank.

*Jar tests – Determination of the optimal dosage*

To deepen the investigation of this treatment step, Jar tests have been performed in order to determine the optimal dosage of aluminum sulfate. Three Jar tests have been done with aluminum sulfate and three with alternative coagulants (see Table 9). The water cooperative introduced to change the coagulant in the WTP due to the effects of aluminum on health and the environment. Therefore, a literature review of different coagulants was done (see Appendix C Table 44). Higher removal capacities of NOM with iron have been shown in case studies (Sillanpaä, Ncibi, & Anu Matilainen, 2017), therefore, ferric chloride and ferrous sulfate were selected to test. Additionally, the option to increase the pH with lime and then add ALUM was tested in a Jar test to present a more economical option to the water cooperative.

*Table 9 Overview coagulants used in Jar tests*

| Coagulant | $Al_2(SO_4)_3*10\ H_2O$ | Lime and $Al_2(SO_4)_3*10\ H_2O$ | Ferric Chloride | Ferrous Sulfate |
|---|---|---|---|---|
| **Performance of test** | 3 times, water samples from different days | 1 time | 1 time | 1 time |
| **Picture (Authors own copyright)** |  |  |  |  |

In the following paragraph, the procedure of the Jar test with aluminum is described, the tests with the alternative coagulants was performed in the same way. A solution has been prepared in 0.5 l (5000 ppm) in the same conditions than in Samaipata, where 1 kg $Al_2(SO_4)_3$ in 100 l is solved (Solar Sibaute J. 2018, personal conversation, 28th April 2018). Six different concentrations (see Table 10) mixed into 800 ml were tested. Started with a concentration of 2.41 mg/l which is used in the WTP, the concentrations increased from mixture to mixture. In the initial water without coagulant, the start pH, color and turbidity have been measured.

*Table 10 Tested concentrations of Aluminum Sulfate [mg/l] and related volume [ml]*

| Mixture | Concentration [mg $Al_2(SO_4)_3$/l] | Volume [ml] |
|---|---|---|
| **1** | 2.41 | 0.2 |
| **2** | 5 | 0.4 |
| **3** | 10 | 0.8 |
| **4** | 12.5 | 1.0 |
| **5** | 15 | 1.2 |
| **6** | 20 | 1.6 |

The pH of the 6 mixtures have been verified to conform with the norm of 6-9 (NB 512). Since the pH was expected to decrease during the experiment, the mixtures with a pH close to 6, were excluded from the test. To enhance the building of flocs the Flocculator SW1 was used to mix the samples 11 min (1 min rapid and 10 min slow) (see Table 10). During the mixing process, the flocculation process has been studied. After 10 min and 20 min of sedimentation, pH and turbidity have been measured. The optimal dosage was determined in regard to a pH (>6) and a decrease of turbidity. In the sample with the optimal dosage, the color was determined and subsequently, the sample was filtrated two times. Afterward, turbidity and color have been measured again.

*Operation of the optimal dosage at the plant*

After the determination of optimal dosage by Jar tests, a new dosage of 15 mg/l aluminum sulfate was tested for 6 h on the 5th of June 2018 at the WTP. The day before the experiment the second chamber of the CFS tank was emptied and cleaned. The inflow at this day was showing 9.91 l/s. A solution of 210 g $AL_2(SO_4)_3$ per liter in a 21 l bucket have been prepared (Calculations see Appendix C Figure 92). The operation has consisted of two parts. In the first part, in pre-experiment on a semi-scale, three different settings have been tested in 200 l barrels to inspect if the new dosage will form flocs as performed in the laboratory. Additionally, the purpose was to demonstrate to the water cooperative, how the coagulant behaves with mixing and without.

The three settings have been tested on the 4th of June 2018:

- 1st barrel 2.41 mg/l with mixing (48.2 ml of the solution in 200 l)
- 2nd barrel 15 mg/l without mixing (300 ml of the solution in 200 l)
- 3rd barrel 15 mg/l with mixing (300 ml of the solution in 200 l)

The fast and slow mixing (1 min fast, 10min slow) have been simulated manually. A change of turbidity has been inspected by taking samples at the beginning of the experiment and after sedimentation (after 2 h and after 18 h).

In the second part of the operation was performed in chamber two in the CFS tank (see Figure 36). Chamber one was completely taken off from the system: no inflow and outflow took place. The inflow of coagulant in chamber one was interrupted and the valve between chamber one and two have been closed. The outflow in the filters was separated from chamber two as well. During the test, it was ensured that no water is going to reach the distribution system. The water from chamber two was drained into the nature during the experiments.

The dosage of 15 mg/l aluminum sulfate was mixed in a 200 l barrel of the experiment (6.421 kg/100 l) and had a reacting time of 3 h before used in the operation. After chamber two was completely filled with water and the pumps were turned on for 6 h with the new dosage. Four samples have been taken in the time period of 1h 30min (calculated retention time) with an assumed freeboard (water level to tank top level) of 30 cm of the basin (see Table 11). The process of flocculation was studied by comparing the interaction of pH, turbidity, alkalinity, and color during the 6 h. The methods used for analyzing can be found in
Table 43 Appendix C Parameter and their methods.

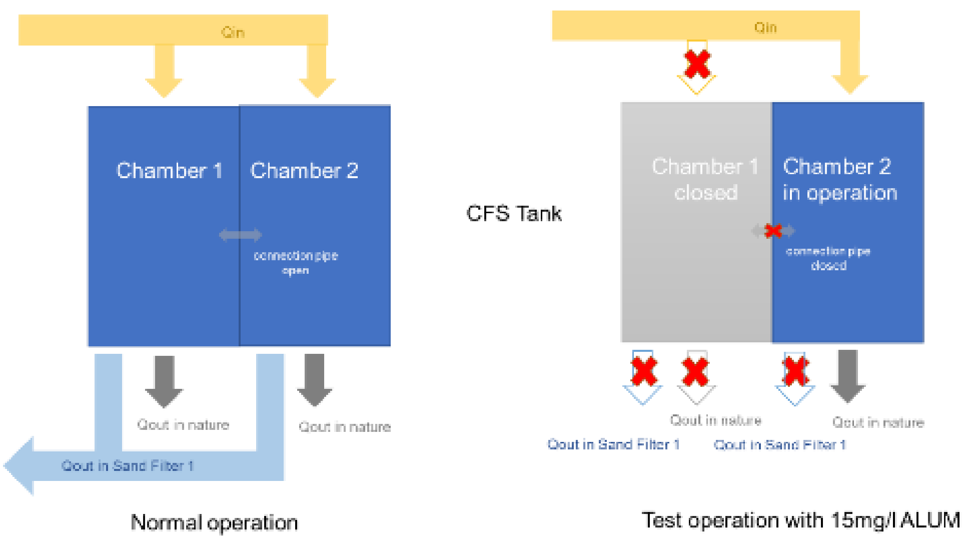



*Figure 36* Overview set ups at the plant during the test operation with 15 mg/L ALUM

*Table 11 Overview sample taking every 4 h*

| Time | | Parameter [-] |
|---|---|---|
| **T= 0 min** | 1:20 pm | pH<br>Turbidity [NTU]<br>Alkalinity [mg $CaCO_3$/L]<br>Color [PtCo] |
| **T= 1.5 h** | 2:50 pm | |
| **T= 3 h** | 4.20 pm | |
| **T= 4.5 h** | 5.50 pm | |

### *Disinfection*

*Table 12 Overview performed tests for the disinfection inspection*

| ***Tests and Calculations*** |
|---|
| ✓ Inspection of the mixing process of the aluminum sulfate<br>✓ Recalculation of the dosage<br>✓ Measurement of residual chlorine |

The preparation and the mixing procedure of calcium hypochlorite have been observed to inspect all the operations done by the technician at the plant. The residual chlorine was measured at three points in the distribution system at two days (2.5.2018 and 4.6.2018) (Appendix C, Figure 89) and the calcium hypochlorite demand (mg/l) was calculated (see Table 13) (see Results Chapter Table 31)

*Table 13 Measurement residual chlorine 2.5.2018 and 4.6.2018*

| ***Residual Chlorine (mg/l)*** | ***Samples & Methods*** |
|---|---|
| **Locations** | P1 Effluent of the plant (Tap)<br>P2 Effluent of the storage tank (Tap)<br>P3 End of the distribution system (Tap) |
| **Equipment** | Kit VULCANO Laboratorio<br><br>*Figure 37 Kit VULCANO Laboratorio June 2018 (Author's own copyright)* |
| **Method** | At situ manually. Barrel will be filled with water (ca. 30 cm). Four drops of solution are added. |

### *Storage tank*

*Table 14 Overview performed tests for the disinfection inspection*

| ***Tests and Calculations*** |
|---|
| ✓ *Calculation of the retention time* |

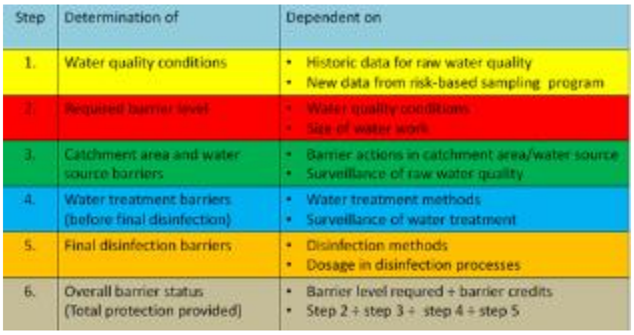
## 4.2.5 Health Risk Assessment

A health risk assessment has been performed for El Fuerte in the second part of the study (desk study in Sweden) and based on gained results on the study in Bolivia. In the beginning, the main contamination sources at the intake have been assessed by a simple semi-quantitative risk matrix based on a Water Safety Plan Method. A matrix evaluates the potential of health risks posed by potential pathogens, coming from potential hazardous events. The matrix describes the likelihood of occurrence of a hazard from almost certain to rare in relation to the health effects on a population from insignificant to catastrophic (WHO & IWA, 2009).

Once that the main contamination sources in the catchment have been defined, the pathogen concentration has been estimated. The evaluated area, the assumptions and calculations can be found in Appendix (see Appendix C Figure 93, Table 45 and Table 46) and the results can be found in Chapter 5.5. E. Coli was analyzed during the water sampling already and therefore excluded in risk assessment.

Following, two methods, a Microbial Barrier Analysis (MBA) to determine the barrier status of the system developed on the guideline in the continuity of the Food Disinfection Practice (Ødegaard H., 2014) and a Quantitative Microbial Risk Assessment (QMRA) with the computational program Analytica were used to further analyze the treatment processes used in the drink water plant.

For the MBA, a scenario with a low and with a high pathogen load was assessed. The steps of the procedure can be found in Figure 38 (also see Appendix C Figure 94 until Figure 100)



| Step | Determination of | Dependent on |
|---|---|---|
| 1. | Water quality conditions | • Historic data for raw water quality<br>• New data from risk-based sampling program |
| 2. | Required barrier level | • Water quality conditions<br>• Size of water work |
| 3. | Catchment area and water source barriers | • Barrier actions in catchment area/water source<br>• Surveillance of raw water quality |
| 4. | Water treatment barriers (before final disinfection) | • Water treatment methods<br>• Surveillance of water treatment |
| 5. | Final disinfection barriers | • Disinfection methods<br>• Dosage in disinfection processes |
| 6. | Overall barrier status (Total protection provided) | • Barrier level requred ÷ barrier credits<br>• Step 2 ÷ step 3 ÷ step 4 ÷ step 5 |

*Figure 38 MBA procedure* (Ødegaard & Østerhus, 2014)

For the QMRA different scenarios variating in pathogen load and settings in the treatment plant were run in the model (Table 15).

*Table 15 Scenarios for the QMRA for El Fuerte*

| Pathogen load | Settings in the treatment plant |
|---|---|
| (A) High load | (1) Actual situation<br>(CFS process and chlorination is not working) |
| (B)10 % of high load<br>(control cow contamination) | (2) The CFS process is working but still chlorination not |
| (C)Low load | (3) The CFS process and the chlorination is working |
| | (4) Additional UV process of 500J/m$^2$ in the WTP |

Finally, a statistical analysis was completed to access the probability of infection for the identified pathogens Campylobacter, Cryptosporidium and Giardia and compared to the recommended value in the annual infection probability less than 1 of 10,000 by the US Environmental Protection Agency (Hunter & Fewtrell, 2001).

In order to estimate the annual infection probability from the obtained data the following formula has been used:

$$\mathbf{P_{annual} = 1 - ((1-P_{inf,\ normal})^{t\ normal}\ (1-P_{inf,\ bad,\ rawwater})^{t,\ bad\_rawwater}\ (1-P_{inf,\ suboptimal})^{t,\ suboptimal}}$$

(Equation 1)

- $P_{annual}$ = annual probability of infection.
- $P_{inf,\ normal}$= daily probability of infection during normal days.
- $P_{inf,\ bad\_rawwater}$ = daily probability of infection during bad raw water quality days.
- $P_{inf,\ suboptimal}$ = daily probability of infection during sub-optimal days.
- $t_{normal}$ = number of normal days.
- $t_{suboptimal}$ = number of suboptimal days.
- $t_{bad\_rawwater}$ = number of bad raw water quality days.

# 5. Results

## 5.1 Information collection of the design of the plant

The collection of material in the office of the Water Cooperative showed that only partially documents of normative references, the planning, and the construction process exits. Instructions for operation and maintenance are lacking in all categories (see Table 16). One finding from comparing the documentation of the construction company is that mentioned technologies named as 'slow filtration' and 'Hydro cyclone' do not existing at the treatment plant.

*Table 16 Listing and comparing collected material from the office of the water cooperative*

| CATEGORY (DVGW W1000/W1010, VDI/ DVGW 6023) | Availability Y=Yes N=No P=Partially available | Document | Details |
|---|---|---|---|
| ***NORMATIVE REFERENCES*** | | | |
| • **Drinking water regulations** | Y | | Reference to NB 512, Ley 1333 |
| • **Environmental regulations** | N | | |
| • **Technical references** | N | | |
| ***PLANNING*** | | | |
| • **Dimensioning** | P | Development of the project report | General data: no design ages, no assumption for dimensioning |
| • **Water Demand** | Y | Water consumption excel sheet | Inhabitants, water tariff 13months, pop. growth |
| • **Environmental investigation** | P | Ground investigation, Environmental investigation | Soil testing, investigation flora & fauna |
| • **Selection of materials** | N | | No selection details/assumptions |
| • **Construction plans** | Y | Plan of construction | Dimensions, construction timetable |
| • **Cost analysis** | Y | | Excavation, building costs |
| ***CONSTRUCTION*** | | | |
| • **Description of the processes WTP** | P | Flocculation tank, Activated Carbon Filters, Sand filters | Dimensions basins, material info of filter, No details storage tank |
| • **Map WTP** | Y | Overview of the plant | |
| • **Sources, Catchments** | P | Data set, Water analysis | Location of the sources, Water analysis 2017 different points in the system |
| • **Description of the distribution system** | Y | Data set | Pipe diameters and locations |

| *OPERATION* | | | |
|---|---|---|---|
| • **Start-up instructions** | **N** | | Personal conversation with technician |
| • **Chemical materials (properties, dosage, protection, storage)** | **Y** | Aluminum sulfate, chlorination instructions | Properties, dosage, solution preparation instructions |
| • **Monitoring of operating parameters** | **N** | | |
| • **Equipment info** | **P** | pH and res. $Cl_2$ Kit, pumps instructions | Instructions for Tés KIT for pH and res. $Cl_2$ measuring, pump details |
| • **Personal list, organizations working at the plant** | **N** | | |
| • **Work regulations** | **N** | | |
| • **Transport and storage** | **N** | | |
| • **Training of personal** | **N** | | |
| • **Security plan (Measurements taken in case of interruption of operation)** | **N** | | |
| • **Documentation of operation** | **N** | | |
| • **Control of the water quality during operation** | **N** | | |
| • **Observation WTP** | **N** | | |
| • **Water protection zones** | **N** | | |
| • **Copies of contracts with companies (lab, maintenance, etc.)** | **N** | | |
| • **Protection equipment for work, first aid** | **N** | | |
| ***MAINTENANCE*** | | | |
| • **Procurement of material** | **N** | | |
| • **Maintenance planning** | **P** | Risk evaluation of the distribution system | |
| • **Responsibilities** | **N** | | |

## 5.2 Investigation of the sources El Fuerte and La Carretera

### 5.2.1 The Source El Fuerte

*Inspection/ Observations*

Geographically, the intake El Fuerte is located at the latitudes 18°10'of South and 63°49' of West, and on an altitude of 1,639 m.a.s.l. The top the Tallada Mountain has a height of 2,130 m. The surrounded park covers an area of 253.6 ha. To investigate the source, the first kilometers a route was available, the last 2 km were hiked under difficult conditions. A gate – unlocked – indicated the track to the source.

The inspected intake can be described as a concrete reservoir with two outlets. One weir leads the flow of the normal river and a tube (with a grid) separates the flow draining to the WTP. The pretreatment grid consists of two layers unoxidized steel filter (2-3 mm).


*Figure 39 (left) Distribution system to the intake of El Fuerte April 2018 (Author's own copyright) & Figure 40 (right) Pretreatment: 2 layers of unoxidized steel filters 2018 (Author's own copyright)*


*Figure 41 (left) Pretreatment at the intake el Fuerte April 2018 (Author's own copyright) & Figure 42 (right) Intake El Fuerte: Lower concrete reservoir April 2018 (Author's own copyright)*

The system has two possibilities for an intake depending on the available amount of water. When the reservoir cannot be filled in the dry season, water is extracted from the upper intake part of the river (approximately 5 m above the reservoir). The upper intake was not possible to access for manual inspection. It is assumed that the upper basin could store approximately 4.5 $m^3$ and the lower basin approximately 160 $m^3$.

The flow was measured to 15 l/s conveyed in the intake pipe 10-12 km to the treatment plant. Two smaller rivers contribute to this flow (Figurita (0 – 1 l/s) and los Alisos (2 – 3 l/s)). The pipe of the intake has a diameter of 10 cm (4"), consists of PVC and connects after 40 m in a distribution pipe of a diameter of 20 cm (8"). The distribution system has existed for over 30 years. During the construction, six people were necessary to transport one section (6 m pipe) the way up to the intake. The distribution system to the WTP has two sedimentation flushes. They are used manual if the water is showing high turbidity. A documentation of this flushing routine did not exist.

Furthermore, four valves were observed on the way to operate the flow, however, most of them are not working probably at the moment.


*Figure 43 (left) Pipes from Los Alisos contributing the flow of El Fuerte (2-3 l/s) April 2018 (Author's own copyright) & Figure 44 (right) Intake El Fuerte: In the background the upper reservoir April 2018 (Author's own copyright)*

No activities of agriculture, residents, industry, or wastewater treatment were found in the catchment area. Wildlife were seen during the hike to the source. Additionally, hints of livestock were noted. Six cow pats were observed close to the river. Further interviews with residents of Samaipata confirmed a free cow farm on top of the mountain. Free cows are estimated on an area of 2,000 ha belonging to 40 different owners. One-fourth of the area belongs to two owners with 120 cows each. Along the river erosion of sand were observed. At the control outlet hints for oxidized iron could were detected. Burned vegetation were observed in some areas from a fire close to the intake at the beginning of the year. At some places in the river trash were detected, e.g. plastic packaging, blankets in the river, construction material.

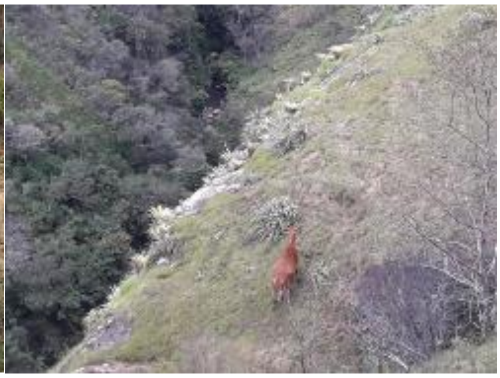



*Figure 45 (left) Cow feces close to the intake April 2018 (Author's own copyright) & Figure 46 (right) Wildlife detected during the intake inspection April 2018 (Author's own copyright)*

The sanitation seal of the collection point of the intake looked in good conditions, no cracks or fissures were visible. No ditches did exist around the intake. There was no fence around the reservoir or the intake. The sanitation tap of the intake was in moderate conditions. The inlet tube of the collection point was completely under water. The reservoir was free of cracks and no algal agglomeration along the basin was detected. The reservoir has one flushing outlet.
The outlet of the intake did not have damages and appeared in good conditions. The chamber of inspection was filled with working materials, such a bucket, a shovel, and was not clean. Water puddles were detected in the area of the outlet. The pipes draining to the treatment plant are over ground. Damages on the surface of the pipes from the fire (d=10 cm) were investigated.

*Figure 47 (left) Valve in the distribution system April 2018 (Author's own copyright) & Figure 48 (middle) Damages on the pipes from fire April 2018 (Author's own copyright) & Figure 49 (right) Chamber of inspection April 2018 (Author's own copyright)*

#### *Protocol for sanitary facilities inspection for rivers*

According to the protocol for sanitary facilities, the risk of contamination of the collection point is ranged with an *amount of* ***25 No´s*** and is related to the range of ***HIGH*** *risk of contamination.*

### 5.2.2 The well La Carretera

#### *Inspection/ Observations*

The ground water well is located approximately 20 m away next to the main street on a territory used as a storage of the Water Cooperative. The well (casted iron) has an age of 30 years, a depth of 130 m and a water level at 40 m below the ground water surface, and can extract a flow of 10 l/s. It is connected to a tank and will be treated at the treatment plant. A documentation of the time in use is not available. The well did not have a sealing and the wellhead was not properly covered. The surrounding of the well was in bad circumstances. Trash and stored material were found everywhere close to the well. A fire burned on the territory to remove trash lying on the ground. The fence was in good conditions, but animals are expected to enter easily. The distribution system is a subsurface pipe and appeared in moderate conditions.

*Figure 50 (left) Territory of the Water Cooperative May 2018 (Author's own copyright) & Figure 51 (middle) Well La Carretera May 2018 (Author's own copyright) & Figure 52 (left) Inspection outlet well La Carretera (Author's own copyright)*

#### *Protocol for sanitary facilities inspection for wells*

According to the protocol for sanitary facilities, the risk of contamination of the collection point is ranged with an *amount of* ***23 No´s*** and is related to the range of ***VERY HIGH*** *risk of contamination.*

## 5.3 Determination of suitable treatment for the type of water source

### 5.3.1 The Source El Fuerte

The water characteristic of El Fuerte is illustrated in Table 17. El Fuerte has increased values of iron and turbidity. In the beginning of April, the river had a turbidity of 7.7 NTU. One month later, the turbidity decreased and was with 5.5 NTU close the standard NB 512. The presence of a high amount of total coliform and E. Coli was detected. According to J. Rodier (2010) El Fuerte showed a high Permanganate Index of 38.46 mg/l.

*Table 17 Water characteristic El Fuerte*

| Source El Fuerte (after pretreatment) | Sample 1 *9th April 2018* | Sample 2 *2nd May 2018* | NB 512 | Unit |
|---|---|---|---|---|
| **pH** | 6.81 | 7.14 | 6.5-9.0 | / |
| **Turbidity** | **7.7** | **5.5** | 5 | NTU |
| **Conductivity** | 31.7 | 34.75 | 1500 | µS/cm |
| **Total Solids** | / | 55.5 | / | mgST/l |
| **TDS** | / | 50.5 | 1000 | mgSTD/l |
| **TSS** | / | 5.0 | / | mgSS7l |
| **Acidity** | / | 5.85 | / | mg$CaCO_3$/l |
| **Alcalinity** | / | 17.96 | 370 | mg/l |
| **Calcium** | / | 2.4 | / | mg$Ca^{2+}$/l |
| **Hardness** | / | 9.5 | < 500 soft | mg$CaCO_3$/l |
| **Chloride** | / | 0.77 | 250 | mg$Cl^-$/L c.I |
| **Total Iron** | **0.33** | **0.52** | 0.3 | mgFe/L |
| **Magnesium** | 0.02 | 0.86 | 150 | mg$Mg^{2+}$/L |
| **Mangan** | / | <0.02 | 0.1 | mgMn/L |
| **Potassium** | / | 2.13 | / | mg$K^+$/L |
| **Sodium** | / | 4.18 | 200 | mg$Na^+$/L |
| **Sulphates** | / | 2.28 | 400 | mg$SO_4$/L |
| **Ammonical Nitrogen** | / | <0.1 | 0.5 | mgN-$NH_3$/l |
| **Carbonates** | / | 17.95 | / | mg/l |
| **Bicarbonates** | / | 17.96 | / | mg/l |
| **Permanganate Index** | / | **38.46** | >4 high* | mg/l |
| **E. coli** | **150** | **61** | <1 | UFC/100 ml |
| **Total Coliform** | **295** | **229** | <1 | UFC/100 ml |

**(J. Rodier, 2010)*

### 5.3.2 The well La Carretera

The water analysis of La Carretera can be found in Table 18. La Carretera showed high values of conductivity, total dissolved solids, sodium, and ammoniacal nitrogen. The Permanganate Index with 24.75 mg/l is high. E. Coli was not present in the well, however, total coliforms were measured with 238 per 100 ml.

The value of total iron with <0.02 mg/l and ferrous iron with 0.24 mg/l cannot be reliable, because ferrous iron should be a part of the total iron and cannot exceed the values of total iron.

*Table 18 Water characteristic Well La Carretera*

| Well La Carretera | Sample *3.5.2018* | NB 512 | Unit |
|---|---|---|---|
| **pH** | 7.79 | 6.5-9.0 | / |
| **Turbidity** | 4.8 | 5 | NTU |
| **Conductivity** | **1730.5** | 1500 | µS/cm |
| **Total Solids** | 976.00 | / | mgST/l |
| **TDS** | **952.00** | 1000 | mgSTD/l |
| **TSS** | 24.00 | / | mgSS7l |
| **Acidity** | 22.23 | / | $mgCaCO_3/l$ |
| **Alkalinity** | **658.68** | 370 | mg/l |
| **Calcium** | 20.4 | / | $mgCa^{2+}/l$ |
| **Carbonate** | <0.01 | / | $mgCaCO_3/l$ |
| **Bicarbonates** | 658.68 | / | mg/l |
| **Chloride** | 167.45 | 250 | mgCl-/L c.I |
| **Hardness** | 120 | >500 hard | $mgCaCO_3/l$ |
| **Total Iron** | **<0.02** | 0.3 | mgFe/l |
| **Ferrous Iron** | **0.24** | / | $mgFe^{2+}/l$ |
| **Magnesium** | 17.08 | 150 | $mgMg^{2+}/L$ |
| **Mangan** | 0.02 | 0.1 | mgMn/L |
| **Potassium** | 5.67 | / | $mgK^{+}/L$ |
| **Sodium** | **514.6** | 200 | $mgNa^{+}/L$ |
| **Sulphates** | 1.14 | 400 | $mgSO_4/L$ |
| **Ammoniacal Nitrogen** | **0.54** | 0.5 | $mgN\text{-}NH_3/l$ |
| **Permanganate Index** | **24.75** | >4 high | mg/l |
| **E. Coli** | 0 | <1 | UFC/100 ml |
| **Total Coliforms** | **238** | <1 | UFC/100 ml |

**(J. Rodier, 2010)*

# 5.4 Evaluation of each treatment process in the treatment plant

## 5.4.1 Coagulation, Flocculation and Sedimentation Tank

- 1 basin: 2 chambers with an area of 160 $m^3$.
- La Carretera and El Fuerte mix in the CFS tank direct.
- $Q_{in,measured}$= 9.6 l/s in a (8'') diameter inlet pipe.
- Retention time: 3.46 h one basin (both in use).
- Coagulant: Aluminum Sulfate with a dosage of 1 kg/100 l = 2.43 mg/l.
- Pump at 18.3 l/h at 35 % and 0.5 bar.
- Mixing: Coagulant is added at beginning in the CFS tank.
- Cleaning: Every 2 weeks sediments will be removed from the bottom of the tank and discharged into the nature.
- Preparation: Every 7 h new mixture (200 l barrel).
- Documentation of operation and maintenance: No.

*Figure 53 (left) Mixing of Aluminum Sulfate 2018 (Author's own copyright) & Figure 54 (right) CFS tank 2018 (Author's own copyright)*


*Figure 55 (left) Stored Aluminum Sulfate 2018 (Author's own copyright) & Figure 56 (right) Filled CFS tank with two chambers 2018 (Author's own copyright)*

- **Inspection of the flocs 9.4.2018:**
  -View from above in the basin: No flocs visible, turbidity.
  -Sample close to the inlet of the CFS tank: No flocs visible, turbidity.
  -Sample close to the outlet: No flocs visible, turbidity.

*Figure 57 (left) Sample close to the inlet of the CFS tank 2018 & Figure 58 (right) Sample close to the outlet 2018 (Author's own copyright)*

- **CFS tank inspection during cleaning process:**
  - No sludge was visible on the basin bottom (only a thin layer in the entrance area).
  - Iron on the pipe (inlet pipe of la Carretera).
  - Algae layers were detected on the bottom.
  - More sediments were found on the bottom in the rainy season.
  - The basin has no gradient on the bottom.
  - The agglomeration of the sediments on the bottom had a green, black and brown colors.

*Figure 59 (left) Empty CFS tank 2018 (Author's own copyright) & Figure 60 (middle) Sediments on the basin bottom 2018 (Author's own copyright) & Figure 61 (right) Outlet of collected sediments 2018 (Author's own copyright)*

On the 9th of April, the raw water pumped into the plant had a characteristic of a high turbidity of 6.4 NTU, a pH of 7, an elevated iron levels of 0.34 mg/l, a high permanganate index of 24.55 mg/l, Total Coliforms of 88 per 100 ml, and E. Coli of 21 per 100 ml. The turbidity in the CFS tank was reduced from 6.2 NTU to 5.9 NTU. The conductivity of 32.45 µS/cm and pH of 6.9 value did not change during this process (see Table 19, Table 20 and Table 21).

*Table 19 Results for raw water sample P1(9.4.2018)*

| P1 Inlet in WTP | Sample 9.4.2018 | NB 512 | Unit |
|---|---|---|---|
| **pH** | 7 | 6.5-9.0 | / |
| **Turbidity** | **6.4** | 5 | NTU |
| **Conductivity** | 32 | 1500 | µS/cm |
| **Permanganate Index** | **24.55** | >4 high* | mg/l |
| **Magnesium** | 0.02 | 150 | mg/l |
| **Total Iron** | **0.34** | 0.3 | mg/l |
| **E. Coli** | **21** | <1 | UFC/100 ml |
| **Total Coliform** | **88** | <1 | UFC/100 ml |

**(J. Rodier, 2010)*

*Table 20 Results for water sample P2 (9.4.2018)*

| P2 Coagulation Tank (close to inlet) | Sample 9.4.2018 | NB 512 | Unit |
|---|---|---|---|
| **pH** | 6.9 | 6.5-9.0 | / |
| **Turbidity** | **6.2** | 5 | NTU |
| **Conductivity** | 32.45 | 1500 | µS/cm |
| **Permanganate Index** | **23.64** | >4 high* | mg/l |

**(J. Rodier, 2010)*

*Table 21 Results for water sample P3 (9.4.2018)*

| P3 Outlet Flocculation Tank | Sample 9.4.2018 | NB 512 | Unit |
|---|---|---|---|
| **pH** | 6.91 | 6.5-9.0 | / |
| **Turbidity** | **5.9** | 5 | NTU |
| **Conductivity** | 32.4 | 1500 | µS/cm |

- **Jar test:**

During Jar tests in the laboratory following coagulant dosages for the water quality in Samaipata were determined (see Table 22 Results of the Jar test). For Aluminum Sulfate the dosage has to increase from 2.41 mg/l to a dosage between 10 and 20 mg/l. For a combination with lime and aluminum sulfate, the concentration of aluminum should be higher than 20mg/l or the pH has to be adjusted.
The result from the Jar tests with iron showed that for $FeCl_3$ more than 20 mg/l is needed to encourage flocs and for $FeSO_4$ a value between 12.5 and 15 mg/l is advised. The detailed results can be found in Appendix D Figure 101 to Figure 106.

*Table 22 Results of the Jar test*

| $Al_2(SO_4)_3$ | $pH_{initial}$ [-] | $Turbidity_{initial}$ [NTU] | Coagulant [mg/l] | $Dosage_{Recommended}$ |
|---|---|---|---|---|
| Test 1 | 6.99 | 5.31 | 15-20 | 10-20 mg/l |
| Test 2 | 7.58 | 6.5 | 12.5 -15 | |
| Test 3 | 7.35 | 6.22 | 10-12.5 | |
| **$Al_2(SO_4)_3$ & Lime $Ca(OH)_2$** | No flocculation visible | | | >20 mg/l or lime adjustment |
| **$FeCl_3$** | No flocculation visible | | | >20 mg/l |
| **$FeSO_4$** | 6.29 | 5.93 | 15 | 12.5-15 mg/l |

Additionally, two samples of the Jar tests were filtrated (Table 23 and Table 24). In a test with ALUM, the turbidity and color were reduced to 0 after filtration. In a second filtration experiment with $FeCl_3$, the initial turbidity decreased from 6.73 to 4.63 NTU. However, the value of color increased from 88mgPt/l in the beginning to 149 mgPt/l after sedimentation and decreased slightly to 128 mgPt/l again.
In a further test, also the influence of filtration alone was inspected. Only the use of filtration reduced turbidity one fourth from 6.73 NTU to 2.83 NTU. The color was reduced from 88 to 71 mgPt/l.

*Table 23 Results of filtration tests with ALUM after the Jar test*

| Fitration 1 - ALUM | | |
|---|---|---|
| | Turbidity [NTU] | Colour [mgPt/l] |
| **Initial** | 6.5 | / |
| **Sedimentation t=20min** | 0.09 | 20 |
| **Filtration** | 0 | 0 |

*Table 24 Results of filtration tests with $FeCl_3$ after the Jar test*

| Filtration 2 - $FeCl_3$ | | |
|---|---|---|
| | Turbidity [NTU] | Colour [mgPt/l] |
| **Initial** | 6.73 | 88 |
| **Sedimentation t=20min** | 5.93 | 149 |
| **Filtration** | 4.63 | 128 |
| **Only Filtration** | **2.83** | 71 |

- **Plant operation:**

The day before the plant operation a semi-scale experiment in the 200 l barrels obtained the following results. In the barrel with 2.41 mg/l of ALUM with mixing and in the barrel with 15 mg/l of ALUM without mixing flocs were not seen. In the third barrel with 15 mg/l Aluminum Sulfate and with mixing (t=14 h) flocs were detected.

*Table 25 Results of the semi-scale experiment in the 200l barrels*

| Barrel | Concentration [mg/l] | Mixing | Observation of flocs | |
|---|---|---|---|---|
| | | | t=20min | t=14h |
| 1 | 2.41 | with | No | No |
| 2 | 15 | without | No | No |
| 3 | 15 | with | No | On the bottom of the barrel |


*Figure 62 Floc formation in the mixture with 15mg/l with mixing after t=14h 2018 (Author's own copyright)*

In the results from the plant operation in one chamber of the WTP can be seen in Figure 62 (4.5 h with a 15 mg/l Aluminum Sulfate). The color increased steadily from 33 to 64 PtCo, as well as turbidity increased from 3 NTU to 5.4 NTU. The value of pH decreased from initial 7.36 to 6.74 in the end.

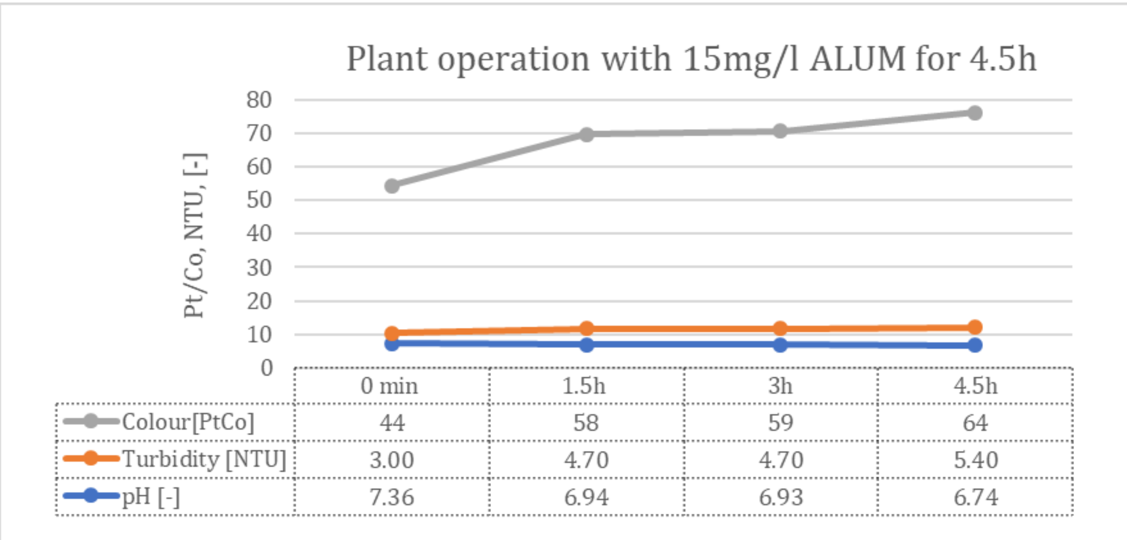



*Figure 63 Results from the plant operation with 15 mg/l ALUM for 4.5 h*

## 5.4.2 Filtration

**Sand filters:**

- 2 Filters in a row with a filter capacity of 50 $m^3$/h.
- Estimated total weight: 4,200 kg, weight of gravel and sand: 3,100 kg.
- Dimensions: Height 1.8 m, diameter 1.5 m, pipe diameter: 7.62 cm (3“).
- Filter material between 0.5, 1, 2, 3, 4, 5, 7 and 10 mm grain size (inflow to outflow).
- $Q_{design}$= 15 l/s.
- Cleaning: Flushing every 3 days, 3-5 min.
- Water Cooperative is not authorized to open the filters.
- 50 cm of the upper finer layer of the first sand filter is missing.
- Documentation of operation or maintenance: No.

*Figure 64 (left) Sand filter in a row (the first 2 unit tanks in the picture) (Author's own copyright) & Figure 65 (right) Sample of the sand (first sand filter) 2018 (Author's own copyright)*

**Activated carbon:**

- Pressurized filter operated at one bar with a flow capacity of 80 $m^3$/h.
- Dimensions: Diameter 1.2 m, Height 2.3 m, Pipe diameter: 7.62 cm (3“).
- Weight of the activated carbon: 500 kg.
- Filter material: Activated carbon (top) and gravel layers (3, 5, 7 and 10 mm grain size (inflow to outflow)).
- $Q_{design}$= 15 l/s.
- Cleaning: Backflush every 5 h with water from the flocculation tank.
- Maintenance: Change of the activated carbon material 2019.
- Documentation of operation and maintenance: No.


*Figure 66 (left) Sample of activated carbon 2018 (Author's own copyright) & Figure 67 (middle) The last filter in the row is the activated carbon filter 2018 (Author's own copyright) & Figure 68 (right) Effluent after backwashing the filters 2018 (Author's own copyright)*

In the inlet of the first sand filter (P3) the turbidity of 5.9 NTU was measured and conductivity of 32.4 µS/cm. After leaving the second sand filter (P4) both parameters increased to 6.45 NTU and 35.45umhos/com (see Table 26) (data 9.4.2018). When comparing this data to the effluent of the activated carbon filter (P5), the turbidity increased to 7.9 NTU and did not comply with the Bolivian standard for drinking water. In the sample of the 2$^{nd}$ of May 2018, the outlet turbidity passed the standard of less than 5 NTU, however, the sample had only a turbidity of 5.5 NTU at the source El Fuerte at this day. In both samples of the outflow of the treatment plant, E. Coli and total coliform were eliminated to 0 per 100 ml. The value of aluminum stayed in the desired limit. The water fulfilled all criteria of the Bolivian drinking water standard except total iron and the Permanganate Index. The Permanganate Index decreased from 38.46 mg/l at the intake of El Fuerte to 15 mg/l at the outlet of the plant, but the value is too high to pass the NB 512 standard (see Table 28).

*Table 26 Results for water sample results P3*

| P3 Outlet Flocculation Tank | Sample 9.4.2018 | NB 512 | Unit |
|---|---|---|---|
| **pH** | 6.91 | 6.5-9.0 | / |
| **Turbidity** | **5.9** | 5 | NTU |
| **Conductivity** | **32.4** | 1500 | µS/cm |

*Table 27 Results for water sample results P4*

| P4 Inlet Activated Carbon Filter | Sample 9.4.2018 | NB 512 | Unit |
|---|---|---|---|
| **pH** | 7.02 | 6.5-9.0 | / |
| **Turbidity** | **6.45** | 5 | NTU |
| **Conductivity** | **35.34** | 1500 | µS/cm |

*Table 28 Results for water sample results P5*

| P5 Outlet Flocculation Tank | Sample 9.4.2018 | Sample 2.5.2018 | NB 512 | Unit |
|---|---|---|---|---|
| **pH** | / | 6.98 | 6.5-9.0 | / |
| **Turbidity** | **7.9** | 4.45 | 5 | NTU |
| **Conductivity** | 44.5 | 38.00 | 1500 | µS/cm |
| **Total Solids** | / | 54.00 | / | mgST/l |
| **TDS** | / | 53.00 | 1000 | mgSTD/l |
| **TSS** | / | 1.0 | / | mgSS7l |
| **Acidity** | / | 5.85 | / | mgCaCO3/l |
| **Alkalinity** | / | 17.96 | 370 | mg/l |
| **Calcium** | / | 2.61 | / | mg$Ca^{2+}$/l |
| **Chloride** | / | 0.69 | 250 | mg$Cl^-$/L c.I |
| **Hardness** | / | 10.00 | < 500 soft | mg$CaCO_3$/l |
| **Total Iron** | / | **0.37** | 0.3 | mgFe/L |
| **Magnesium** | / | 0.85 | 150 | mg$Mg^{2+}$/L |
| **Mangan** | / | <0.02 | 0.1 | mgMn/L |
| **Potassium** | / | 2.18 | / | mg$K^+$/L |
| **Sodium** | / | 4.08 | 200 | mg$Na^+$/L |
| **Sulphates** | / | 2.28 | 400 | mg$SO_4$/L |
| **Aluminum** | / | 0.05 | 0.1-0.2 | mg/l |
| **Ammoniacal Nitrogen** | / | <0.1 | 0.5 | mgN-$NH_3$/l |
| **Permanganate Index** | / | **15.00** | >4 high* | mg/l |
| **E. Coli** | 0 | 0 | <1 | UFC/100 ml |
| **Total Coliform** | 0 | 0 | <1 | UFC/100 ml |

**(J. Rodier, 2010)*

### 5.4.3 Disinfection

- Disinfectant: Calcium Hypochlorite in a concentration of 1.41 mg/l (with assumed purity of 65 % at an influent of 9.6 l/s).
- Preparation: Every 8-10 h a new mixture in a barrel (200 l), 600 g diluted in 100 l.
- Mixing process: After filtration pumped with 18.3 l/h at 50 %.
- Documentation: No.
- Inspection of the mixing process: The mixing process was assessed as not accurate. There was still the old mixture available when the technician added the new dosage. The barrel was not cleaned before preparing a new mixture.



*Figure 69 Sample of Calcium Hypochlorite 2018 (Author's own copyright) & Figure 70 Mixing of the disinfectant 2018 (Author's own copyright) & Figure 71 Inspection of the mixing routine of the technician 2018 (Author's own copyright)*

In comparison to the outlet to the treatment plant (P6) the turbidity increases from 7.9 NTU to 9.2 NTU after passing the storage tank (data 9.4.2018). Measuring the turbidity at the end of the distribution system the values decreases again to 6.45 NTU. From the inlet point in the plant, the permanganate index of 23.64 mg/l grows to 29.43 mg/l (data 9.4.2018). The value for aluminum did not exceed the admissible value of the NB 512 (Table 30).

*Table 29 Results for water sample P6*

| P6 After the storage tank | Sample 9.4.2018 | NB 512 | Unit |
|---|---|---|---|
| **Turbidity** | **9.2** | 5 | NTU |
| **Permanganate Index** | **29.43** | >4 high* | mg/l |

**(J. Rodier, 2010)*

*Table 30 Results for water sample P7*

| P7 Coagulation Tank (close to inlet) | ***P7.1 Tap*** *(city center)* **9.4.2018** | **P7.2 Tap** *(close to WTP)* **2.5.2018** | NB 512 | Unit |
|---|---|---|---|---|
| **pH** | 7.19 | 6.85 | 6.5-9.0 | / |
| **Turbidity** | **6.45** | **5.0** | 5 | NTU |
| **Conductivity** | 41.7 | 43.29 | 1500 | µS/cm |
| **Alkalinity** | / | 13.97 | 370 | mg/l |
| **Aluminum** | / | **0.04** | 0.1-0.2 | mg/l |

The free chlorine was measured at the effluent of the treatment plant with less than 0.3-0.5 mg/l with a corresponding demand of 1.01 mg/l. At the end of the distribution system, less 0.2 or no residual chlorine was left in the water with a corresponding demand 1.31-1.41 mg/l (Table 31).

*Table 31 Results for the residual chlorination measurement in three points*

| **Location** | **$Cl_2$ residual [mg/l]** | | **NB 512 [mg/l]** | **Dosed Calcium Hypochlorite** | **Demand [mg/l]** |
|---|---|---|---|---|---|
| | **2.5.2018** | **4.6.2018** | | | |
| **P1 Effluent of WTP** | <0.3 | <0.5 | 1.5 | 1.41 | 1.01 |
| **P2 After the storage tank** | <0.5 | <0.5 | 1.5 | 1.41 | 0.91 |
| **P3 End of distribution system** | <0.2 | <0.2 | 1.5 | 1.41 | 1.31 |

### 5.4.4 Storage Tank

- Volume: 200 $m^3$.
- Cleaning: 1/month.
- Retention time: 5.87 h.
- Appearance during the inspection: Turbid water, hints for iron (pipes).

### 5.4.5 Surrounding

- Fence: Possibility for animals to enter.
- Lock on the entrance: The plant was not always locked.
- Small storage house on the plant: Storage of material and laboratory (but empty).

## 5.5 Health risk assessment

### 5.5.1 Simple semi-quantitative risk matrix

The considered pathogens for Samaipata are illustrated in Table 32 (Considerations to the scored can be found in Appendix D Table 47). The risk matrix shows that the most risk was ranked to Cryptosporidium and E. Coli 0157 in the category moderate and almost certain. In the category moderate and likely the pathogens Campylobacter, Giardia and viruses scored. Salmonella was expected to occur once per year; therefore, it was ranked in the field unlikely moderate.

*Table 32 Risk Matrix at the intake Samaipata*
**X1= E. Coli, X2= Campylobacter, X3= Cryptosporidium, X4= Giardia, X5= Salmonella, X6= Viruses*

| Likelihood | Insignificant | Minor | Moderate | Major | Catastrophic |
|---|---|---|---|---|---|
| Almost Certain | | | X1, X3 | | |
| Likely | | | X4, X2, X6 | | |
| Moderately Likely | | | | | |
| Unlikely | | | X5 | | |
| Rare | | | | | |

### 5.5.2 Microbial Barrier Analysis (MBA)

Using population size and the water classification level, the required barrier level was found for each of the scenarios. Under normal load conditions the required barrier level was determined to be **5.5 bacteria (b) + 5.5 viruses (v) + 3.5 protozoa (p)**. Under high load conditions the required barrier level changed to become **5.5b + 5.5v + 4.5p**.

The next step to completing an MBA is to determine if there are any regulations in place protecting the catchment area and water source. For Samaipata, no catchment area and water source barrier were determined in step three. Further log credits are determined by the water treatment barriers implemented at the treatment plant before final disinfection. The log reduction for coagulation + sedimentation + filtration would remove **2.5b + 1.75v + 2.5p.** Due to the lack of non-monitoring, a deduction of the log-credit of 40% was assumed. The total log credit after this deduction was found to be **1.5b + 1.05v + 1.5p**.

The final disinfection barrier at the treatment plant is chlorination. The concentration of the chlorine dosage was determined at the inspection visit at the plant with 1.41 mg/l. TOC was assumed with 2.5 mg/l and the effective time with 174 min. The calculated values can be found in Table 33. To determine the log reduction following equation was used, $log_{reFduction} = n*Ct_{calculated} / Ct_{required}$. The n values were taken from literature and are also listed in Table 33. The log reduction from chlorination was determined to be **72.36b + 16.08v + 0.64p**.

The final step to the MBA procedure is to subtract from the required barrier level the summed log reductions from all components. Under normal conditions the overall barrier status, or the total protection provided is **- 68.36b – 11.63v + 1.93p**. For the high pathogen loads, the overall barrier status was determined to be **- 68.36b – 11.63v + 2.36p**.

The negative numbers clearly show that the barrier for bacteria and viruses is larger than required to disinfect the raw water. In the treatment for protozoa's the treatment technologies in Samaipata are not sufficient to provide a secure drinking water supply.

*Table 33 Results of the MBA*

| MBA/GDP procedure | | Option 1 | Option 2 | Assumptions |
|---|---|---|---|---|
| STEP | Determination of | normal conditions | high pathogen load conditions | |
| 1 | Water quality conditions | Case: **Da**, < 0.01$p^2$ | Case: **Dc**, >0,01$p^2$ | |
| 2 | Required barrier level | **5.5b+5.5v+3.5p** | **5.5b+5.5v+4.5p** | 1,000-10,000 PE |
| 3 | Catchment area and water source barriers | / | / | No restrictions |
| 4 | Water treatment barriers (before final disinfection) | 2.5b+1.75v+2.5p<br>=(1-0.4) *(2.5b+1.75v+2.5p)<br>**=1.5b+1.05v+1.5p** | 2.5b+1.75v+2.5p<br>=(1-0.4) *(2.5b+1.75v+2.5p)<br>**=1.5b+1.05v+1.5p** | 1) Coagulation + sedimentation + filtration (turbidity produced water <0,2 NTU)<br>2) Online-monitoring is lacking: Deduction of log-credit 40% |
| 5 | Final disinfection barriers | IF= 0.58272mg/l<br>Ct= 0.82728mg/l<br>k= 0.016mg/l<br>$Ct_{calc}$ = 48.24 mg min/l<br>n=3b+3v+2p<br>Ct= 2b+9v+150p<br>=72.36b+16.08v+0.64p | IF= 0.58272mg/l<br>Ct= 0.82728mg/l<br>k= 0.016mg/l<br>$Ct_{calc}$ = 48.24 mg min/l<br>n=3b+3v+2p<br>Ct= 2b+9v+150p<br>=72.36b+16.08v+0.64p | V=200$m^3$, Q= 9.6l/s, Average t10/F=0.5, 1 chamber PF= 1.0<br>$t_{eff}$= (V/Q)*(t10/F)*PF= 173.61min= 2.89h<br>Assumption: TOC= 2.5mg/l in chamber, 20mg/l influent<br>Dose= 1.41mg/l<br>IF = 0,06 · TOC + 0,36 · Cdose + 0,08 · (Cdose / TOC) – 0,12<br>Ct=Cdose-IF<br>k=0,013*TOC-0,04*Ct-0,01*Ct/TOC+0,02<br>$Ct_{calc}$= (Ct/k)*(1 – e(-k·t))<br>Table, 0.5°C, pH 7-8<br>$log_{red}$ = n · $Ct_{calc}$/ $Ct_{req}$<br>no UV |
| 6 | Overall barrier status (Total protection provided) | **-68.36b-11.63v+1.36p** | **-68.36b-11.63v+2.36p** | **Reduction of risk of p required** |

### 5.5.3 Quantitative Microbial Risk Assessment (QMRA)

Giradia, Cryptosporidium, and Campylobacter from livestock and wildlife in the catchment area were contributing to the assumed pathogen load coming to the treatment plant. The Input data for the feces [n/l] for the QMRA for high pathogen load, reduced pathogen load (10 % high load), and low pathogen load can found in Table 35 and Table 36.

The standard health target was an infection rate of less than $10^{-4}$ people annually. After running the program and calculating the $P_{Annual}$ the following outcomes were obtained. Case 1 (the current system: flocculation and disinfection failure) did not pass the standard (see Table 35). In case 2, when the flocculation works with an assumed failure of 120 h/a, the treatment did not pass the standard. In the third test, flocculation and chlorination were assumed to work in optimal conditions. In this scenario Campylobacter had an annual infection rate less than the 1 of 10,000 people in all three pathogen load scenarios. Additionally, Giardia passed with a low load of pathogens. The final case, an addition of a UV technology (500J/m$^2$) in the treatment plant showed the best results. In the high load scenario 1 of 3 pathogens and with a reduced load 2 of 3 pathogens complied with the standard. In the scenario with an assumed low load Giardia and Campylobacter passed the standard and the Cryptosporidium was close to pass with 4 of 10,000 infected people a year (see Table 36).

The QMRA has shown, that Cryptosporidium was the hardest pathogen to remove by the treatment technologies. The best outcome was performed with an addition of an ultraviolet disinfection.

Table 34 shows the log reduction by the treatment processes as an output of the Analytica program for case 4. (The column additional barrier 3 and ultrafiltration is 0 because it is not used in this study.) For the elimination for Campylobacter free chlorination, UV disinfection and the conventional treatment had the highest influence. In every treatment step Giardia is removed. Cryptosporidium is not removed by free chlorination. The most impact in the treatment showed the addition of a UV disinfection unit.

*Table 34 Log reduction by treatment progress for case 4*

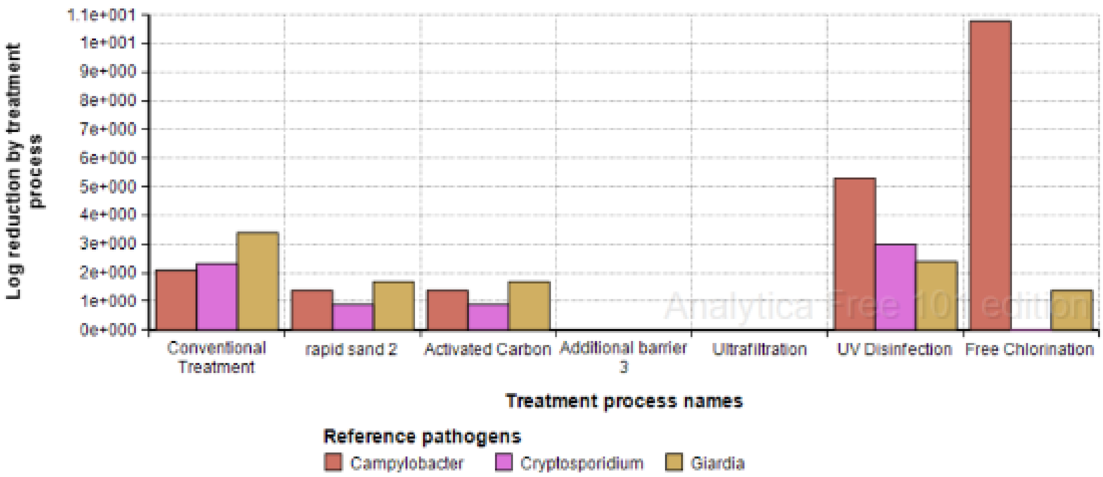


*Table 35 Results for QMRA case 1 and case 2*

| CASE 1 | | INPUT Pathogens | | OUTPUT | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Present situation | Scenario | 1 | 2 | 1 | | 2 | | Pannual | <1/10000 |
| | Conditions season | Dry | Rainy | Dry | | Rainy | | | |
| | Pathogen concentration | | | Pinf, normal | Pinf, suboptimal | Pinf, normal | Pinf, suboptimal | | |
| | t [days] | | | 36 | 146 | 36 | 147 | | |
| High load | Giardia | 27.08E+04 | 9.016E+04 | 7.39E-04 | 7.67E-01 | 2.46E-04 | 4.28E-01 | 1.00E+00 | NO |
| | Cryptosporidium | 0.47E+04 | 0.16E+04 | 2.44E-02 | 6.27E-01 | 8.8E-03 | 5.72E-01 | 1.00E+00 | NO |
| | Campylobacter | 0.9E+04 | 0.3E+04 | 2.44E-02 | 6.62E-01 | 8.8E-03 | 5.04E-01 | 1.00E+00 | NO |
| Protection of the source (10% of high load) | Giardia | 6.77E+04 | 2.25E+04 | 1.85E-04 | 3.49E-01 | 6.15E-05 | 1.4E-01 | 1.00E+00 | NO |
| | Cryptosporidium | 0.12E+04 | 0.04E+04 | 7.53E-02 | 5.60E-01 | 3.17E-02 | 4.83E-01 | 1.00E+00 | NO |
| | Campylobacter | 0.23E+04 | 0.15E+04 | 6.25E-03 | 4.35E-01 | 4.41E-03 | 3.53E-01 | 1.00E+00 | NO |
| Low load | Giardia | 27E+00 | | 7.37E-08 | 1.85E-04 | 2.93E-10 | 1.85E-04 | 5.28E-02 | NO |
| | Cryptosporidium | 0.4E+00 | | 2.79E-05 | 2.16E-03 | 3.95E-08 | 2.22E-03 | 4.75E-01 | NO |
| | Campylobacter | 1.0E+00 | | 2.76E-06 | 3.51E-04 | 1.48E-11 | 3.72E-04 | 1.01E-01 | NO |

| CASE 2 | | INPUT Pathogens | | OUTPUT | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Flocculation is fixed (120h not working) | t [days] | Dry | Rainy | 180 | 2 | 180 | 3 | Pannual | <1/10000 |
| High load | Giardia | 27.08E+04 | 9.016E+04 | 7.39E-04 | 7.67E-01 | 2.46E-04 | 4.28E-01 | 9.92E-01 | NO |
| | Cryptosporidium | 0.47E+04 | 0.16E+04 | 2.44E-02 | 6.27E-01 | 8.8E-03 | 5.72E-01 | 1.00E+00 | NO |
| | Campylobacter | 0.9E+04 | 0.3E+04 | 2.44E-02 | 6.62E-01 | 8.8E-03 | 5.04E-01 | 1.00E+00 | NO |
| Protection of the source (10% of high load) | Giardia | 6.77E+04 | 2.25E+04 | 1.85E-04 | 3.49E-01 | 6.15E-05 | 1.4E-01 | 7.42E-01 | NO |
| | Cryptosporidium | 0.12E+04 | 0.04E+04 | 7.53E-02 | 5.6E-01 | 3.17E-02 | 4.83E-01 | 1.00E+00 | NO |
| | Campylobacter | 0.23E+04 | 0.15E+04 | 6.25E-03 | 4.35E-01 | 4.41E-03 | 3.53E-01 | 9.87E-01 | NO |
| Low load | Giardia | 27E+00 | | 7.37E-08 | 1.85E-04 | 2.93E-10 | 1.85E-04 | 9.38E-04 | 9.38 of 10000 |
| | Cryptosporidium | 0.4E+00 | | 2.79E-05 | 2.16E-03 | 3.95E-08 | 2.22E-03 | 1.59E-02 | NO |
| | Campylobacter | 1.0E+00 | | 2.76E-06 | 3.51E-04 | 1.48E-11 | 3.72E-04 | 2.31E-03 | NO |

*Table 36 Results for QMRA case 3 and case 4*

| CASE 3 | | INPUT Pathogens | | OUTPUT | | | | Pannual | <1/10000 |
|---|---|---|---|---|---|---|---|---|---|
| **Flocculation and chlorination is fixed (120h not working)** | t [days] | Dry | Rainy | 180 | 2 | 180 | 3 | | |
| High load | Giardia | 27.08E+04 | 9.016E+04 | 1.54E-05 | 3.78E-02 | 2.99E-05 | 2.45E-02 | 1.48E-01 | NO |
| | Cryptosporidium | 0.47E+04 | 0.16E+04 | 1.52E-01 | 6.27E-01 | 1.65E-01 | 5.79E-01 | 1.00E+00 | NO |
| | Campylobacter | 0.9E+04 | 0.3E+04 | 0.00E+00 | 0.00E+00 | 1.13E-12 | 4.64E-11 | 3.43E-10 | << 1/10000 |
| Protection of the source (10% of high load) | Giardia | 6.77E+04 | 2.25E+04 | 3.82E-06 | 9.53E-03 | 2.49E-06 | 6.22E-03 | 3.82E-02 | NO |
| | Cryptosporidium | 0.12E+04 | 0.04E+04 | 7.20E-02 | 5.63E-01 | 3.08E-02 | 4.83E-01 | 1.00E+00 | NO |
| | Campylobacter | 0.23E+04 | 0.15E+04 | 0.00E+00 | 0.00E+00 | 1.83E-13 | 2.36E-11 | 1.04E-10 | << 1/10000 |
| Low load | Giardia | 27E+00 | | 1.54E-09 | 3.87E-06 | 2.98E-09 | 7.48E-06 | 3.10E-05 | 3.1 of 100000 |
| | Cryptosporidium | 0.4E+00 | | 3.83E-05 | 2.12E-03 | 3.87E-06 | 2.15E-03 | 1.81E-02 | NO |
| | Campylobacter | 1.0E+00 | | 0.00E+00 | 0.00E+00 | 1.23E16 | 1.55E-14 | 6.66E-14 | << 1/10000 |

| CASE 4 | | INPUT Pathogens | | OUTPUT | | | | Pannual | <1/10000 |
|---|---|---|---|---|---|---|---|---|---|
| **Flocculation, chlorination is fixed, UV added (500J/m²) (120h failure a year)** | t [days] | Dry | Rainy | 180 | 2 | 180 | 3 | | |
| High load | Giardia | 27.08E+04 | 9.016E+04 | 1.19E-07 | 2.98E-04 | 1.19E-07 | 1.21E-12 | 3.65E-02 | NO |
| | Cryptosporidium | 0.47E+04 | 0.16E+04 | 4.79E-04 | 2.47E-02 | 4.98E-04 | 5.76E-01 | 9.39E-01 | NO |
| | Campylobacter | 0.9E+04 | 0.3E+04 | 0.00E+00 | 7.08E-16 | 0.00E+00 | 4.69E-15 | 1.53E-14 | << 1/10000 |
| Protection of the source (10% of high load) | Giardia | 6.77E+04 | 2.25E+04 | 2.97E-08 | 9.89E-09 | 9.89E-09 | 2.48E-05 | 8.17E-05 | 0.817 of 10000 |
| | Cryptosporidium | 0.12E+04 | 0.04E+04 | 1.38E-04 | 4.14E-05 | 3.52E-05 | 2.23E-03 | 3.73E-02 | NO |
| | Campylobacter | 0.23E+04 | 0.15E+04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.16E-16 | 0.00E+00 | 0 |
| Low load | Giardia | 27E+00 | | 7.73E-10 | 1.94E-06 | 1.19E-11 | 2.98E-08 | 4.11E-06 | 0.04 of 10000 |
| | Cryptosporidium | 0.4E+00 | | 1.17E-06 | 8.87E-05 | 3.91E-10 | 2.23E-06 | 3.95E-04 | 4 of 10000 |
| | Campylobacter | 1.0E+00 | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |

# 6. Discussion

The obtained results of the investigated system are discussed, and recommendations are given in this chapter. An overview of the recommendations and an implementation plan for the Water Cooperative is presented in *CHAPTER 7.*

## 6.1 Sources

### 6.1.1 The Source El Fuerte

El Fuerte showed expected values for a source water intake with a high number of pathogens, high turbidity and high natural organic material (WHO, 2011). Indication for natural organic material can be referred to the Permanente Index, which had a value of 38.46 mg/l and is significantly high (J. Rodier, 2010).

The water analysis has shown that the operation of the WTP has to be adjusted to different water qualities variating during the year. For instance, the turbidity showed high values in rainy season and almost acceptable values close the Bolivian standard in rainy season.

The reduction of total iron seemed to be one main reason to build the treatment plant in 2017 when reviewing the papers of the construction company. The presence of iron was detected with high values up to 0.52 mg/l and also visible during the investigation of El Fuerte. The brown water puddles next to the control valve indicated iron occurrence in the ground (Ing. A. Mercado, personal conversation, 2018).

The contribution of the two smaller rivers was not investigated during this study, their impact on the water quality of El Fuerte would be an important insight for further investigations. Comparing the values of the sample taken from El Fuerte and P1 it leads to the assumption that parameters like E. coli, total coliform and turbidity decreased because of the dilution from the two smaller rivers.

One interesting finding was that one third of the flow of 15 l/s from El Fuerte is already supplying 45-50 houses between the intake and the WTP. The water is not treated for these houses and not safe for water consumption. Alternative water supply for these houses between El Fuerte and the inlet of the treatment plant is required.

The source scored a high risk of contamination due to the livestock activities on top of intake. One recommendation is to reduce the contamination load by protection measures to avoid animals to enter and to get in direct contact with the water source (e.g.: a fence along the intake area). Further inspection has to be done to assess how the catchment area is used above the intake of El Fuerte. It would be important to know how many cows have access to the upper part of El Fuerte and to how much of the land is owned by investors. The Water Cooperative is responsible to protect their water source from contamination and must ban or restrict activities close the catchment area (WHO, 2011). The Water Cooperative is also advised to remove the trash from the inspection box at the intake and from the river. The inspection box needs to be free of working material and must be cleaned. Additionally, the pipes attacked by the fire have to be replaced.

Since there are less plans of the operation at the plant, the Water Cooperative is advised to start with a documentation of the work of the technician in charge of the source El Fuerte. For instance; which flow does he measure? How many times he uses the flushing vales and what is was the turbidity at this day? Are there changes in the water quality of El Fuerte?

### 6.1.2 The well La Carretera

The described change of taste of the water from the residents when mixing La Carretera and El Fuerte can be caused by the increased values of the well La Carretera (Ing. A. Mercado, personal conversation, 2018). The permanganate Index which can indicate high organic material (24.75 mg/l) and the total coliforms (238 in 100 ml) are unexpectedly high for groundwater extraction and could introduce a contamination of the well (O'Connor, et al. 2009).

In accordance to the finding from the sampling, the protocol of risk of contamination with a score of *very high* has shown lacks in the protection of La Carretera, which could be triggered by the human activities close to the well. Boreholes show a high contamination potential; therefore, it is important to maintain safe distances between groundwater wells and possible sources of contamination (DVGW, 2006). The Environment Agency (2009) states that wells need to be free of any human activity in a radius of 50 m. In distance of 500 m agricultural, traffic facilities, fuel storage and in the whole aquifer recharge area landfills, livestock farming or underground disposal should to be forbidden by the responsible community. Therefore, its recommended to fix the sealing and the cover of the well and establish a protection area around La Carretera (no storage of material, no animals, no fire, no trash, etc.).

In regards of a source mix it can be said that both sources have water quality characters which are good in complementing each other in their properties. For instance, the high values of alkalinity from la Carretera can be useful for El Fuerte to stabilize the pH in the CFS tank to be less sensitive to changes (buffer capacity) and to encourage the chemical flocculation (O'Connor, et al. 2009). In agreement with water and environmental technology expert Olof Bergstedt a mixing of La Carretera 1/3 and El Fuerte of 2/3 is recommended for Samaipata (personal communication, 2019). Additionally, it is also advised to unite the flow before the flocculation tank to balance the waters characteristic.

## 6.2 Treatment plant

### 6.2.1 Coagulation, Flocculation and Sedimentation tank

The removal of particles is often the first step in a treatment chain. Particles and organic material which are not removed in this step can lead to impacts on the efficiency of the followed technologies (Drinan, 2001). In Samaipata this treatment step seems to be essential because of the high Permanganate Index (24.55 mg/l) and seasonal high values of turbidity (6.4 NTU) reaching the plant.

The study detected problems in the ability of forming flocs:

- During the inspection no building of flocs was noted, normally it is possible to see the formed cluster already by eye in the tank.
- Furthermore, during the investigation of the tank almost no agglomeration of sludge on the tank bottom was found.
- In comparison of the particles on the bottom of the basin in Samaipata to the sludge formed during the Jar test in the laboratory the color of the flocs appeared green and black in Samaipata. In the Jar Test in the laboratory where the flocculation worked optimal the color of the sludge was beige.
- The calculated dosage of ALUM of 2.41 mg/l was detected as too low to form flocs and is recommended be greater than 5mg/l (A. Mercado, personal conversation, May 2018).
- The water analysis also strengthens the assumption. Even if the turbidity decreased slightly from 6.2 NTU to 5.9 NTU, the pH did not change. Decreasing in turbidity and pH are used in monitoring of coagulation to give indication of a chemical reaction of the coagulant (Ogutu C.B.A., et al., 2011).

One explanation can be the low dosage of the coagulant at the treatment plant. The Jar test showed that the dosage of ALUM should range between 10-20 mg/l. In regard to the negative health aspects of Aluminum, the Cooperative introduced their interest to change Aluminum Sulphate to an alternative coagulant. In the study aluminum, however, proved to stay in the limits of the Bolivian standards at the effluent.

Considering alternatives for ALUM, coagulants with iron can be a suitable solution for the water treatment, due to their increased effectiveness of removal of NOM. The use of aluminum sulfate with the adjustment of lime can also be an option. But due to the difficulty in controlling and surveillance of two chemicals at the same time during operation, it is recommended to choose only one coagulant for the plant in Samaipata.

Applying a new coagulant dosage, it should be mentioned that the optimal dosage depends on the daily water quality in the inlet of the plant. The study detected that especially El Fuerte has seasonal variations of the characteristic on which the treatment has to respond differently. The dosages found out in the Jar tests should not be applicated easily at the plant. A simple Jar test system (flocculator) is recommended to be implemented at the treatment plant and the optimal dosage of the coagulant has to be determined regularly to the actual water quality (Water Works Association, 2012).

Besides that, an operational monitoring of indicators of the water quality is highly recommend. A plan should be made by the Cooperative which measurements has to be performed during the daily routine of the technician: What? When? Who? Where? For primary set ups of the instruments and the performance of the Jar test the Cooperative should be advised by a water expert. The results have to be documented. According to Japan Water Works Association (2012) following parameters are suggested for installation of water quality instruments in a water treatment plant:

*Table 37 Suggested measurements at the treatment plant according to Japan Water Works Association (2012):*

| Place - Where? | Parameter – What? |
|---|---|
| **El Fuerte** | Turbidity, pH, alkalinity, ammonia, conductivity, temperature, chlorine demand |
| **La Carretera** | Turbidity, pH, alkalinity, ammonia, conductivity, temperature, chlorine demand |
| **Coagulation, flocculation, sedimentation basin** | Turbidity, pH, residual chlorine |
| **Filtration (outlet AC filter)** | Turbidity, pH, residual chlorine, particle counter, color |
| **Chlorination** | Residual, pH |
| **Storage tank (effluent)** | Turbidity, color, pH, residual chlorine |

The plant operation with 15 mg/l of ALUM (5th of June 2018) in semi-scale in the barrels and in the tank demonstrated that even if the optimal dosage will be applied mixing zones are necessary to install for the formation of flocs.

The flocs are not formed in the tank because the coagulant need fast and slow velocities zones to form the particles. The interactions of the measured parameters during the plant operation can be explained like this: The pH and color values increased due to the increased amount of coagulant over time. The increased dosage of coagulant led to a steady drop of the values of pH. Only in the small-scale experiment in the barrels where 15 mg/l of ALUM and mixing was applied coagulation happened.

At the moment the sources are mixing direct in the CFS tank without fast and slow mixing zones, therefore a technical solution needs to be installed in Samaipata. A solution is illustrated in Figure 72 and has to be applied on both chambers. The inlet part of the basin has to be separated in chambers, in which mechanical mixers has to be installed. The more chambers, the better the ability to form flocs. Different velocities, first a fast rotation flowed by a slow rotation mixing should be operated. Shammas & Wang (2016) emphasizes that for coagulation a time of 0.5-2 min for mixing and a time for flocculation of 15-30 min should be guaranteed in the different zones. Building the chambers can be realized from local material.

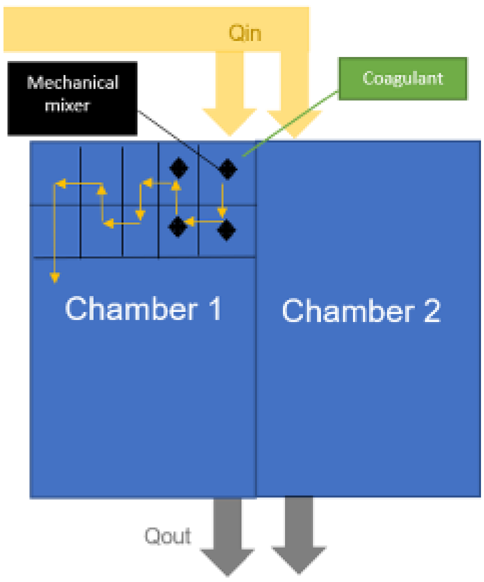



*Figure 72 Recommended technical solution for the CFS (the water flow is marked in yellow)*

### 6.2.2 Filtration

As a result from the evaluation of the filtration processes the desired removal efficiency was not performed in the filter processes. Contrary to the expected was noted, the turbidity has increased from the inlet of the first filter steadily to the outlet of the activated carbon filter, from 5.6 NTU to 7.9 NTU comparing the data from April. Iron most commonly is removed during the filtration process; however, the removal effect was also not fulfilled in regard to the Bolivian standard with a limit to 0.3 mg/l. In combination with the assumption of the failure of the CFS tank, it can be assumed that the load of particles which have to be removed in the CFS tank, instead was clogged in filters. It can be assumed that this inhibited the further efficiency of the removal rate of particles (O'Connor, 2009).

The operation was only assessed from the water analysis because it was not possible to open the filters without the permission of the construction company. Further work is required to establish the assumptions of filter clogging. For instance, it would be interesting to investigate the grain size of the filter material and to verify the flow rates of the filters (Activated Carbon 80 $m^3/h$ and sand 50 $m^3/h$).

During this study, tests to investigate the filtration ability in combination with the Jar Test were performed. The tests showed that filtration alone without coagulation, filtration sedimentation reduced turbidity from 7.3 to 2.83 NTU and color from 88 to 71 mgPt/l. This could let to the suggestion that insufficiencies are caused by the wrong operation of the filters.

One recommendation for the Water Cooperative is to backflush the filter material with cleaned water from the effluent. Currently they are cleaning the filter with water from the coagulation tank which is not optimal. Additionally, as recommended from the construction company the activated carbon material should be replaced in 2019.

### 6.2.3 Chlorination and storage tank

The investigation detected issues within the chlorination process in the storage tank. The results of the residual chlorine measurement detected evidence that chlorine is oxidized after leaving the plant. At point P3 (tap in a house) which is only 500m from the WTP away, no residual chlorine was measured anymore. Taken together this founding with the result from the effluent analysis of the Permanganate Index of 15 mg/l, it can be suggested that the high amount of organic material is consumed by the disinfectant, and possible undesired by products of chlorine are formed (Drinan, 2001).

A surprising finding was the increase of the Permanganate Index to a double of 29.43 mg/l after leaving the plant. As well as the turbidity which has grown from 7.9 mg/l to 9.2 mg/l. During this study an inspection of the storage tank from inside could not be realized, however, this could be important to gain more insights of the contamination issue in the storage tank and could be recommended for further investigation.

Forming by-products from chlorine during disinfection is associated with health effects (Drinan, 2001) and control measures of the natural organic matter has to be implemented to decrease the amount before reaching the point of chlorination. As mentioned before, it is assumed that the coagulation, flocculation and sedimentation process is not working correctly, which also has influences on the filters. These processes aim to remove NOM and particles (Matilainen A. et al., 2002). It would be recommended to the Cooperative to improve coagulation and filtration first, and subsequently investigate how the system will interact. An enhancement of these processes can already decrease the amount of NOM, chlorination could work properly, and no additional solution would be necessary.

This study was unable to give explanations why the turbidity from the outlet of the storage tank decline from 9.2 NTU (P6) to 6.45 NTU (P7) in a distance of 500 m. One hypothesis may be water losses in the pipe system, however, due to the high uncertainties about the location and conditions of the pipes, the water Cooperative should start to investigation the distribution system in a further project to get deeper insights.

## 6.3 Distribution system and other sources

This study did not focus on all water sources in Samaipata and the distribution system in detail. However, the investigation of the total system is highly recommended to the Cooperative to develop an informative overview about the water quality of the village. Complete mapping of the distribution system and further research in the pipe system (sanitary inspection) should be performed to check the conditions (e.g. creaks, breaks, missing, etc.) and identify the deficiencies of the system (e.g. water losses). After inspecting, a replacement of old parts of the old pipe system is advised. Additionally, installations of water meters in system can provide a more accurate flow data.

Regarding the outcome of the study, the Cooperative should improve the restrictions and protection of El Fuerte and la Carretera, and it is suggested to inspect and assess the risk of contamination of the other water intakes as well.

Concerning fecal contamination of sources, ground water extraction has to secured with minimum one barrier treatment e.g. disinfection (WHO, 2011). The Cooperative is experienced in the application with calcium hypochlorite at the treatment plant, therefore it could be adopted for chlorinating at the other wells as well. An additional benefit from that would be the provision of more points for secondary disinfection in the distribution system to avoid recontamination of the pipes (AWWA, 2011).

## 6.4 Health Risk Assessment

Even if the result of the effluent of the treatment plant (P5) showed that E. Coli and total coliforms were eliminated, the health risk assessment detected lacks in the treatment of the pathogens. The QMRA and MBA showed that the system needs to be improved in the reduction of protozoa. A. Omarova et al. (2018) states that viruses and bacteriophages are considered to be more resistant in deactivation by chlorine than vegetative bacterial cells like E. coli. The protozoa Cryptosporidium is one of the most resistant microorganisms in the water (A. Omarova et al. 2018). An implementation of UV treatment to improve disinfection performance at the plant is recommended.

The QMRA proved that a UV treatment only can provide an appropriate treatment considering that all other treatments will work optimal (flocculation and disinfection). Before an implementation of a UV technology is recommended, the high amount of natural organic material and turbidity must be decreased due to their negative effects on the removal effectiveness (C. G. Okpara et al., 2011).

In field tests on the community level in South Africa, UV disinfection has proven as capable as a reliable disinfection method with low maintenance costs (every 6 months), and low electivity costs from renewable energies (A. Gadgil, 1998). It is advised to combine a UV technology at the plant with the existing chlorination to provide a residual disinfection in the distribution system against regrowth of pathogens (A. M. Zyara et al. 2016).

Additionally, the simulations in the QMRA showed that a higher source protection (control of the number of free cows or a fence) leads to a less input load in the plant and has a positive impact on the yearly infection rate.

## 6.5 Administration and general recommendation for the Water Cooperative

The Water Cooperative had almost no plans of the operation or maintenance available. The Water Cooperative is advised to start documenting of the operation by the technician at the treatment plant, the distribution system, and the sources. The WHO Water safety plan (WSP) should be considered when planning for the future. This will be useful get an overview about the processes at the WTP and changes in the water quality. When the responsible technician retires the knowledge will get lost and in most in most cases it might be impossible to continue with the work.

Additionally, the Water Cooperative needs to clarify the lifetime of the material and technologies used at the plant. A maintenance plan needs to be created when to replace or repair materials in the sanitation system. For mechanical equipment 5-10 years are foreseen as maintenance period, for wells, storage tanks and water treatment facilities 10-15 years are considered according to Jordan J. (2010).

A major fact, which is influencing the operation at the plant is the change of the members of the Water Cooperative every two years. With a complete fresh line-of members after every period expertise gets lost. The treatment plant needs minimum one qualified person which is charge of the water quality permanently in a long-term perspective.

To apply the recommendations from this report the Water Cooperative can take guidance for by a water expert (e.g.: by CASA laboratory). The results from this study, cannot easily be applied on the system, e.g.: the optimal dosage of the coagulant. It needs to be pointed out, that the study mainly aimed to investigate the issues of the treatment system and detect deficiencies. Further research at the plant need to be done to adjust the findings to the current water conditions.

# 7. Overview recommendations and implementation process

This chapter prioritizes the recommendations given in this thesis and assists the Water Cooperative to perform the improvements. The recommendations implemented in two phases shall provide the Water Cooperative guidance to structure the first planning process.

Priority 1 includes all recommendations, which are highly suggested and crucial without the treatment in Samaipata will not work optimally. Priority 2 can be implemented afterwards to change the water treatment in Samaipata to a sustainable drinking water supply.

***Priority 1 - Highly recommended for an optimal work of the treatment:***

- Source protection of El Fuerte and La Carretera.
- Protection of the catchment area of the sources (e.g.: fence, etc.).
- Reparation of the sealing and the cover of the well.
- A Mixing of La Carretera in a relation of 1/3 to El Fuerte 2/3 will complete the water quality of the sources.
- Documentation of operation steps.
- Implementation of a laboratory at the site of the WTP.
- Monitoring and documentation of the water quality daily/ weekly (What? When? Who? Where?).
- Guidance of an expert for optimal operation of the treatment steps at the plant.
- Qualification of a person working permanent on the water quality analysis at the site of the WTP.
- Implementation of a Jar Test equipment at the site of the WTP.
- Backwash the filter with effluent water.
- Replacement of the activated carbon and sand in the filters as mentioned by the construction company.
- Implementation of a rapid and slow mixing zone and a mixer in CFS tank.

***Priority 2 - Recommended for a sustainable drinking water supply:***

- Risk assessment of the other sources of Samaipata.
- The sources need to be mixed before the WTP.
- Inspection and assessment of the cow contamination.
- Chlorination of all wells.
- Consideration of the Water Safety Plan form WHO for future planning.
- Removal of the trash from the river and inspection box.
- Creation of a maintenance plan for 15-20 year (lifetime of material & technologies).
- Drainage of the CFS tank effluent and sludge not into nature.
- Change to an iron coagulant.
- Further investigation of the material of the filters (e.g.: Grain-size distribution, flow rates, etc.).
- Completing the mapping of the distribution system.
- Replacement old pipes.
- A sanitation inspection of the pipe system.
- Alternative water supply for the 45-50 houses above the WTP.
- Replacement of the pipes damaged from the previous fire.
- Implementation of UV treatment to improve disinfection performance.

# 8. Conclusions

The water supply and sanitation face major challenges in developing countries, such as investment in the sanitation sector, conditions of the water structure and public appreciation for the value of water.

After evaluating the drinking water treatment plant in Samaipata in terms of performance, design, operation, and maintenance, it can be summarized:

- The main detected issues in the water system were a lack of protection of the two sources, a lack of skilled expertise to operate the treatment plant, a lack of guidance in administration, insufficient design and missing equipment for drinking water treatment, and incomplete technologies at the treatment plant.
- To provide a safe water consumption *from Source to Tap* and get a more detailed overview of the deficiencies of the water system, further investigation of the water system in Samaipata are highly advised, especially the distribution network.
- The provided 2-step implementation plan of *Priority 1 - highly recommended for an optimal* and *Priority 2 - Recommended for a sustainable drinking water supply* will assist the Water Cooperative to prioritizes the recommendations given in this thesis.
- The safe water provision of Samaipata will depend on the awareness of the value of the Water Cooperative.

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# Appendix

## Appendix A Declaration of Academic Honesty

I, Michaela Karolina Braun, hereby confirm that the Master Thesis titled

*Performance Evaluation of a Drinking Water Treatment Plant in Samaipata, Bolivia*

is solely my own work and that every text passage, figure or diagram from books, papers, the Web or any other source copied or in any other way used has been acknowledged and fully cited.

Gothenburg, 2019 Michaela Karolina Braun

# Appendix B Background

*Figure 73 Appendix B Residual Chlorine test pool in Samaipata (2018) (Author’s own copyright)*

*Figure 74 Appendix B Sediments from the tap water (2018) (Author’s own copyright)*

*Figure 75 Appendix B (left) Effluent of the WTP (CASA, 2018) and Figure 76 Appendix B (right) Effluent of the Storage Tank at the Plant (CASA, 2018)*

*Figure 77 Appendix B Water bubbles after filling a glass with tap water. They are disappearing after 20 seconds (2018) (Author's own copyright).*

# Appendix C Methodology

## Protocol for sanitary facilities inspection for rivers

Date and Time: ______________________________

Climate: ______________________________

Temperature: ______________________________

Persons attenting the inspection: ______________________________

**<u>Gerneral information</u>**

Name of investigated river: ______________________________

Direction: ______________________________

Altitude: ______________________________

Name of the operator: ______________________________

Age of the system: ______________________________

*Table 38 Appendix C Questions to evaluate the risk of contamination of a river*

| Category | Question | Yes | No | Comment |
|---|---|---|---|---|
| **A** | **Surrounding and first impression** | | | |
| | 1. Does the water appear without notable conspicuousness in appearance or odor?<br>2. Does the sanitation sealing appear in good conditions? (Are there cracks/ fissures?)<br>3. Does a fence exist around the source or on the way to the source?<br>4. Does the fence appear in good conditions? Can animals enter through the fence?<br>5. Are excreta of animals visible close to the fence? Or close to the intake?<br>6. Does a ditch exist?<br>7. Is the zone next to intake free of trash, water puddles or plants?<br>8. Does the inlet of the intake appear in good conditions?<br>9. Is a prefiltration available?<br>10. Is the size of the filtration bigger than 0.5 m?<br>11. Does a side inspection box exist?<br>12. Does the side inspection box have a top cover? | | | |

| | | | | |
|---|---|---|---|---|
| | 13. Does the side inspection box and the top cover appear in good conditions?<br>14. Is the side inspection box free of sediments inside?<br>15. Are there permanent residents upstream the catchment area?<br>16. Are there contribution activities of wastewater and trash upstream the catchment?<br><br>Comments: | | | |
| **B** | **Inlet point of intake** | | | |
| | 1. Are the pipes complete subterranean?<br>2. Are there cracks or fissures visible?<br>3. Does the intake appear in good conditions?<br>4. Is the intake free of sediments?<br><br>Comments: | | | |
| **C** | **Reservoir in front of the intake** | | | |
| | 1. Are there cracks or fissures visible?<br>2. Is there a valve?<br>3. Does the valve appear in good conditions?<br>4. Does the interior of the reservoir appear clean and free of sediments or algae?<br>5. Does the inlet pipe appear in good conditions?<br>6. Are there any damages at the inlet pipe?<br>7. Have there been a fence around the reservoir?<br>8. Does the fence appear in good conditions?<br>9. Can animals enter the reservoir?<br>10. Does the environment appear normal around the reservoir?<br>11. Does a pretreatment exist in front of the inlet of the reservoir?<br>12. Does the pretreatment appear in good conditions?<br>13. Is there any trash or sediments visible at the inlet of the reservoir?<br><br>Comments: | | | |

| | | | | |
|---|---|---|---|---|
| **D** | **Outlet of intake** | | | |
| | 1. Does the chamber of inspection appear in good conditions?<br>2. Does the chamber of inspection is free of sediments, trash, water puddles?<br>3. Does the outlet look in good conditions?<br>4. Have there been any damages on the outlet pipe?<br>5. Does the<br><br>Comments: | | | |
| **E** | **Distribution from the source to the WTP** | | | |
| | 1. Is the distribution system subterranean?<br>2. Are there damages visible on the pipes?<br>3. Do the valves appear in good conditions?<br>4. Do the control taps appear in good conditions?<br>5. Is there a continues supply of water?<br><br>Comments: | | | |

**Risk of contamination:**

Amount of NO's in total: ____________________

| | | |
|---|---|---|
| Between 32-43 No's | ☐ | Very High |
| Betwenen 19-31 No's | ☐ | High |
| Between 8-18 No's | ☐ | Low |
| Between 7 and less No's | ☐ | Very Low |

Risk of contamination: _______________________

**Remarks:**

Observations:

________________________________________

________________________________________

________________________________________

________________________________________

Limitation in the field:

**<u>Drawing of the intake:</u>**

**<u>Drawing of the pipes/ dimensions:</u>**

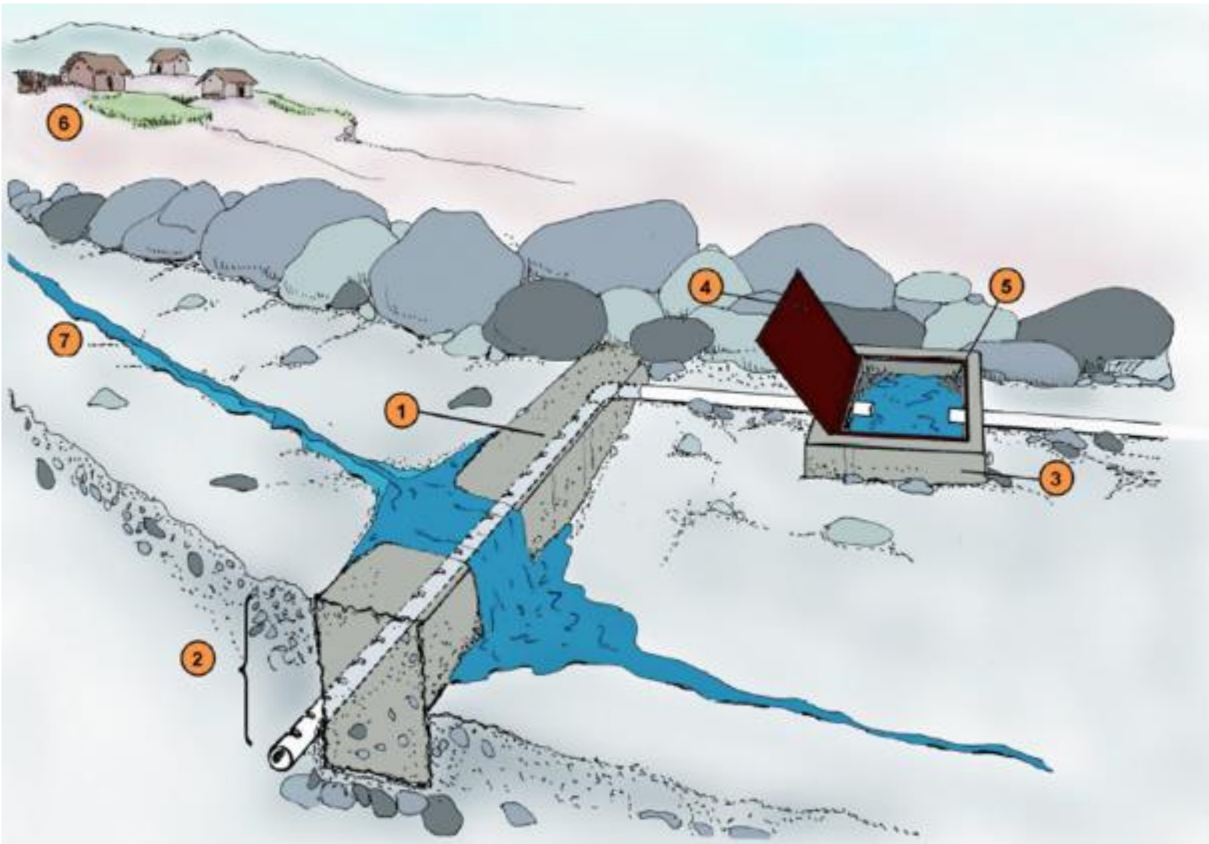



*Figure 78 Appendix C Inspection map of the river intake (CASA; 2009)*

## Protocol for sanitary facilities inspection for wells

Date and Time: ____________________________________________

Climate: ____________________________________________

Temperature: ____________________________________________

Persons attenting the inspection: ______________________________

**Gerneral information**

Name of investigated well: ______________________________

Direction: ____________________________________________

Altitude: ____________________________________________

Name of the operator: ______________________________

Age of the well: ____________________________________________

Depth of the well: ____________________________________________

Water level in the well:______________________________

Excavated well: ☐ or perforated well: ☐

*Table 39 Appendix C Questions to evaluate the risk of contamination of a well*

| Category | Question | Yes | No | Comment |
|---|---|---|---|---|
| **A** | **Circumstance well** | | | |
| | 1. Does a sealing of the well exist?<br>2. Does the sealing of the well appear in good conditions without cracks or damages?<br>3. Is the artesian well 50 cm above the superficial?<br>4. Is the well head properly covered?<br>5. The zone around the well is free of trash water puddles or plants?<br>6. Does there exist a fence?<br>7. Can animals enter the zone through the fence?<br>8. Does a crown ditch exit?<br>9. Does the crown ditch appear in good conditions?<br>10. Is the area around 30 m free of latrines?<br><br>Comments: | | | |

| | | | | |
|---|---|---|---|---|
| **B** | **Transmission line well to tank** | | | |
| | 1. Do the pipes and other elements in the transmission line are free of water puddles?<br>2. Is the flow control valve of the well protected?<br><br>Comments: | | | |
| **C** | **Tank** | | | |
| | 1. Are walls of the tank free of cracks and is the tank closed?<br>2. Does there is a sanitary inspection cover?<br>3. Is the cover free of cracks and fissures?<br>4. Is the cover secured with a padlock?<br>5. Is the inside of the tank clean and free of algae and sediments?<br>6. Is the ventilation pipe free of plugging and has a mesh that protects the entry of birds?<br>7. Is the overflow pipe free of plugging and has a mesh that protects the entry of birds?<br>8. Does the flushing pipe appear in good conditions and is free of plugging?<br>9. Do the stairs have a protection?<br><br>Comments: | | | |
| **D** | **Distribution system** | | | |
| | 1. Is the distribution network totally subterranean?<br>2. Is the distribution network in good conditions<br>3. Is the distribution system without visible water puddles?<br>4. Do the public extraction points have pedestals? Are these in good conditions without water puddles?<br><br>Comments: | | | |
| **E** | **Supply/ Others** | | | |
| | 1. Is the supply 24/7?<br>2. Is there enough pressure in all points in the distribution system?<br>3. Does a treatment (e.g. disinfection) exist? If yes, is there a documentation of the chlorination process? | | | |

**Risk of contamination:**

Amount of NO's in total: ________________

| | | |
|---|---|---|
| Between 21-28 No's | ☐ | Very High |
| Betwenen 13-20 No's | ☐ | High |
| Between 6-12 No's | ☐ | Low |
| Between 5 and less No's | ☐ | Very Low |

Risk of contamination: ____________________

**Remarks**

Observations:

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

Limitation in the field:

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

**Drawing of the well:**

**Drawing of the pipes/ dimensions:**

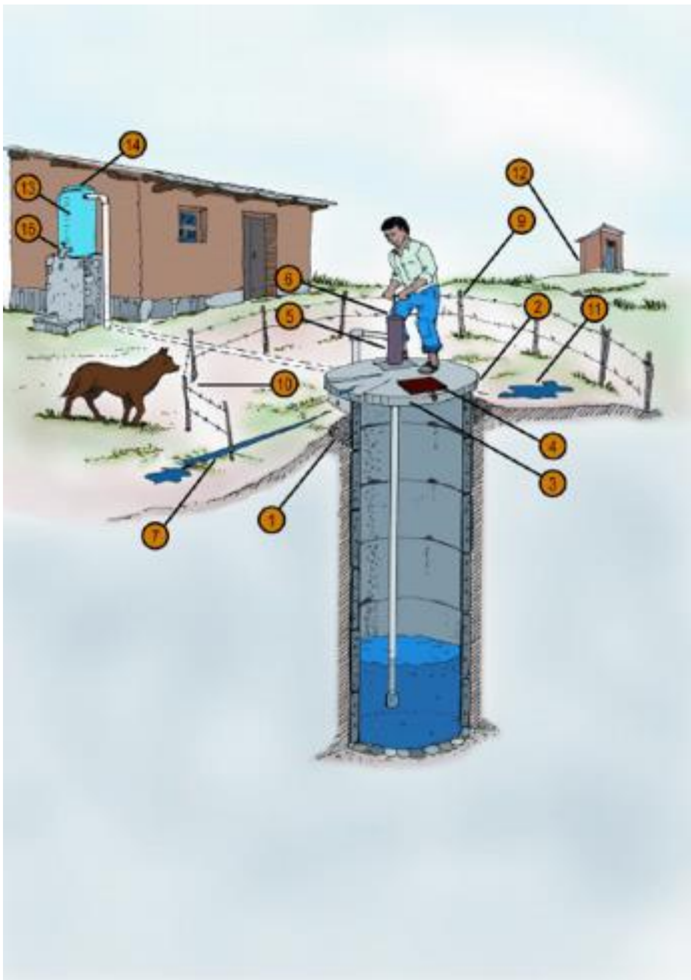



*Figure 79 Appendix C Inspection map of a well (CASA, 2009)*

*Table 40 Appendix C Measured parameter El Fuerte and La Carretera*

| ***El Fuerte (9.4.2018)*** | ***El Fuerte (2.5.2018)*** | ***La Carretera (2.5.2018)*** |
|---|---|---|
| pH [-] | pH [-] | pH [-] |
| Turbidity [NTU] | Turbidity [NTU] | Turbidity [NTU] |
| Permanganate Index [mg/l] | Permanganate Index [mg/l] | Permanganate Index [mg/l] |
| Conductivity [µS/cm] | Conductivity [µS/cm] | Conductivity [µS/cm] |
| Fe [mg/l] | Total Solids [mgST/l] | Total Solids [mgST/l] |
| E. Coli [UFC/100 ml] | TDS [mgSTD/l] | TDS [mgSTD/l] |
| Total Coliform [UFC/100 ml] | TSS [mgSS7l] | TSS [mgSS7l] |
| | Acidity [$mgCaCO_3$/l] | Acidity [$mgCaCO_3$/l] |
| | Alkalinity [mg/l] | Alkalinity [mg/l] |
| | Calcium [$mgCa^{2+}$/l] | Calcium [$mgCa^{2+}$/l] |
| | Hardness [$mgCaCO_3$/l] | Hardness [$mgCaCO_3$/l] |
| | Chloride [$mgCl_-$/L c.I] | Chloride [mgCl-/L c.I] |
| | Total Iron [mgFe/L] | Total Iron [mgFe/L] |
| | Magnesium [$mgMg^{2+}$/L] | Magnesium [$mgMg^{2+/}$L] |
| | Mangan [mgMn/L] | Mangan [mgMn/L] |
| | Potassium [mgK/L] | Potassium [mgK/L] |
| | Sodium [$mgNa^+$/L] | Sodium [mgNa+/L] |
| | Sulphates [$mgSO_4$/L] | Sulphates [$mgSO_4$/L] |
| | Ammoniacal Nitrogen [mg/l] | Ammoniacal Nitrogen [mg/l] |
| | Carbonates [mg/l] | Carbonates [mg/l] |
| | Bicarbonates [mg/l] | Ferrous Iron [$mgFe^{2+/}$l] |
| | E. Coli [UFC/100 ml] | E. Coli [UFC/100 ml] |
| | Total Coliform [UFC/100 ml] | Total Coliform [UFC/100 ml] |

*Table 41 Appendix C Measured parameters in the WTP*

| ***P1 Influent WTP*** | ***P2 Entrance CFS Tank (after mixing with coagulant)*** | ***P3 Effluent CFS Tank*** |
|---|---|---|
| pH [-] | pH [-] | pH [-] |
| Turbidity [NTU] | Turbidity [NTU] | Turbidity [NTU] |
| Conductivity [µS/cm] | Conductivity [µS/cm] | Conductivity [µS/cm] |
| Fe [mgFe/L] | Permanganate Index [mg/l] | |
| Mn [mgMn/L] | | |
| Permanganate Index [mg/l] | | |
| E. Coli [UFC/100 ml] | | |
| Total Coliform [UFC/100 ml] | | |
| ***P4 Inlet Activated Carbon Filter*** | ***P5.1 $Q_{effluent}$ (point of Chlorination)*** | ***P5.2 $Q_{effluen}$t (point of Chlorination)*** |
| pH [-] | pH [-] | pH [-] |
| Turbidity [NTU] | Turbidity [NTU] | Turbidity [NTU] |
| Conductivity [µS/cm] | Conductivity [µS/cm] | Conductivity [µS/cm] |
| | Permanganate Index [mg/l] | Total Solids [mgST/l] |
| | E. Coli [UFC/100 ml] | TDS [mgSTD/l] |
| | Total Coliform [UFC/100 ml] | TSS [mgSS7l] |
| | | Acidity [mgCaCO3/l] |
| | | Alkalinity [mg/l] |
| | | Calcium [$mgCa^{2+}$/l] |
| | | Chloride [$mgCl^{-}$/L c.I] |
| | | Hardness [$mgCaCO_3$/l] |
| | | Total Iron [mgFe/L] |
| | | Magnesium [$mgMg^{2+}$/L] |
| | | Mangan [mgMn/L] |
| | | Potassium [mgK/L] |
| | | Sodium [mgNa+/L] |
| | | Sulphates [$mgSO_4$/L] |
| | | Aluminum [mg/l] |
| | | Ammoniacal Nitrogen [mg/l] |
| | | Permanganate Index [mg/l] |
| | | E. Coli [UFC/100 ml] |
| | | Total Coliform [UFC/100 ml] |
| ***P6 Effluent Storage Tank*** | ***P7.1 End Distribution System*** | ***P7.2 End Distribution System*** |
| Turbidity [NTU] | pH [-] | pH [-] |
| Permanganate Index [mg/l] | Turbidity [NTU] | Turbidity [NTU] |
| | Conductivity [µS/cm] | Conductivity [µS/cm] |
| | | Alkalinity [mg/l] |
| | | Aluminum [mg/l] |

*Table 42 Appendix C Protocol of sampling at the sources and the WTP*

| Location of sample | Parameter [unit] | Notes/Picture |
|---|---|---|
| **Source**<br>**El Fuerte**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm]<br>P. Index [mg/l]<br>E. coli [UFC/100ml]<br>Total Coli. [UFC/100ml]<br>Fe [mg/l] | -Time: 1pm sunny/humid<br>-Place: Control outlet of the lower reservoir/ inlet in the pipe to the WTP<br>-Appearance: turbid<br>-Outlet from a PVC tube (10.16 cm)<br>-Appearance of the collection point: bad-normal<br>-Pretreatment exists after the small reservoir<br><br>*Figure 80 Appendix C Sample taking at the source (Author's own copyright)* |
| **Source**<br>**El Fuerte**<br><br>**2.5.2018** | pH [-]<br>Turbidity [NTU]<br>P. Index [mg/l]<br>Conductivity [µS/cm]<br>Total Solids [mgST/l]<br>TDS [mgSTD/l]<br>TSS [mgSS7l]<br>Acidity [mg$CaCO_3$/l]<br>Alkalinity [mg/l]<br>Calcium [mg$Ca^{2+}$/l]<br>Hardness [mg$CaCO_3$/l]<br>Chloride [mg$Cl^-$/L c.I]<br>Total Iron [mgFe/L]<br>Magnesium [mg$Mg^{2+}$/L]<br>Mangan [mgMn/L]<br>Potassium [mgK/L]<br>Sodium [mg$Na^+$/L]<br>Sulphates [mg$SO_4$/L]<br>Ammoniacal Nitrogen [mg/l]<br>Carbonates [mg/l]<br>Bicarbonates [mg/l]<br>E. Coli [UFC/100 ml]<br>Total Coliform [UFC/100 ml] | -Time: 11.30 am cloudy<br>- Place: Control outlet of the lower reservoir/ inlet in the pipe to the WTP<br>-Appearance: turbid<br>-Outlet from a PVC tube (10.16 cm)<br>-Appearance of the collection point: bad-normal<br>-Pretreatment exists after the small reservoir |

| | | |
|---|---|---|
| **La Carretera**<br><br>**2.5.2018** | pH [-]<br>Turbidity [NTU]<br>Permanganate Index [mg/l]<br>Conductivity [µS/cm]<br>Total Solids [mgST/l]<br>TDS [mgSTD/l]<br>TSS [mgSS7l]<br>Acidity [mg$CaCO_3$/l]<br>Alkalinity [mg/l]<br>Calcium [mg$Ca^{2+}$/l]<br>Hardness [mg$CaCO_3$/l]<br>Chloride [mg$Cl_-$/L c.I]<br>Total Iron [mgFe/L]<br>Magnesium [mg$Mg^{2+}$/L]<br>Mangan [mgMn/L]<br>Potassium [mgK/L]<br>Sodium [mg$Na^+$/L]<br>Sulphates [mg$SO_4$/L]<br>Ammoniacal Nitrogen [mg/l]<br>Carbonates [mg/l]<br>Ferrous Iron [mg$Fe^{2+}$/l]<br>E. Coli [UFC/100 ml]<br>Total Coliform [UFC/100 ml] | -Time: 11:10 am, cloudy, rainy<br>-Sampling point: Direct from the well (casted iron pipe)<br>-Appearance of the collection point: very bad (waste, fire, animals, etc.)<br>-Appearance of the sample: clear, hints for iron in the water<br><br>*Figure 81 Appendix C Extraction La Carretera (Author's own copyright)* |
| **Inlet in the plant**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm]<br>Fe [mgFe/L]<br>Mn [mgMn/L]<br>Permanganate Index [mg/l]<br>E. Coli [UFC/100 ml]<br>Total Coliform [UFC/100 ml] | -Time: 11:20 pm sunny/humid<br>-Place: tube inlet in the plant<br>-Appearance: turbid<br>-Outlet from a PVC tube<br>-Appearance of the collection point: normal<br><br>*Figure 82 Appendix C Inlet in the plant, sample taking from the right pipe (Author's own copyright)* |
| **Inlet CFS Tank**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm]<br>Permanganate Index [mg/l] | -Time: 10.30 am sunny/humid<br>-Place: in the basin 0.3-0.5 m from the surface<br>-Appearance: turbid, no flocs<br>-Outlet from a PVC tube<br>-Appearance of the collection point: normal |

| | | |
|---|---|---|
| **Outlet CFS Tank**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm] | -Time: 10.39 am sunny/humid<br>-Place: Tap in the treatment system<br>-Appearance: turbid, no flocs<br>-Outlet from a FG tube<br>-Appearance of the collection point: normal<br><br>*Figure 83 Appendix C Point of sample before the sand filters, the upper tap was used to take a sample (Author's own copyright)* |
| **Inlet Activated Carbon Filter**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm] | -Time: 10.48 am sunny/humid<br>-Place: tap in the treatment system<br>-Appearance: turbid<br>-Outlet from a FG tube<br>-Appearance of the collection point: normal<br><br>*Figure 84 Appendix C Extraction point before activated carbon filter (Author's own copy right)* |
| **Outlet of the Treatment Plant**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm]<br>Permanganate Index [mg/l]<br>E. Coli [UFC/100 ml]<br>Total Coliform [UFC/100 ml] | -Time: 10.59 am sunny/humid<br>-Place: after disinfectant dosage, before tank, tap in the treatment system<br>-Appearance: turbid, acid smell<br>-Outlet from a FG tube<br>-Appearance of the collection point: normal |

| | | |
|---|---|---|
| | | <br>*Figure 85 Appendix C Extraction point outlet of treatment plant (blue tap) (Author's own copy right)* |
| **Outlet of the Treatment Plant**<br><br>**2.5.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm]<br>Total Solids [mgST/l]<br>TDS [mgSTD/l]<br>TSS [mgSS7l]<br>Acidity [mg$CaCO_3$/l]<br>Alkalinity [mg/l]<br>Calcium [mg$Ca^{2+}$/l]<br>Chloride [mg$Cl^-$/L c.I]<br>Hardness [mg$CaCO_3$/l]<br>Total Iron [mgFe/L]<br>Magnesium [mg$Mg^{2+}$/L]<br>Mangan [mgMn/L]<br>Potassium [mgK/L]<br>Sodium [mg$Na^+$/L]<br>Sulphates [mg$SO_4$/L]<br>Aluminum [mg/l]<br>Ammoniacal Nitrogen [mg/l]<br>Permanganate Index [mg/l]<br>E. Coli [UFC/100 ml]<br>Total Coliform [UFC/100 ml] | -Time: 12:15 am, cloudy, rainy<br>-Place: after disinfectant dosage, before tank, tap in the treatment system<br>-Appearance: turbid, acid smell<br>-Outlet from a FG tube<br>-Appearance of the collection point: normal |
| **After the storage Tank**<br><br>**9.4.2018** | Turbidity [NTU]<br>Permanganate Index [mg/l] | -Date: 11.05 am sunny/humid<br>-Place of the sample: After the tank<br>-Point of sampling: Tap<br>-Outlet from a FG tube<br>-Appearance: turbid, MO, acid smell<br>-Bad appearance of the tab (old, corrosion) |

| | | |
|---|---|---|
| | |  *Figure 86 Appendix C Sampling point after the storage tank (Author's own copyright)* |
| **Tap in the City (End distribution system)**<br><br>**9.4.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm] | -Time: 1 pm sunny/humid<br>-Treatment exists<br>-Place: Bathroom city center<br>-Appearance: turbid<br>-Point of sampling: Tap<br>-Outlet from a FG tube<br>- Appearance of the collection point: bad<br><br>*Figure 87 Appendix C Tap in the city (Author's own copyright)* |

| | | |
|---|---|---|
| **Tap (End distribution system)**<br><br>**2.5.2018** | pH [-]<br>Turbidity [NTU]<br>Conductivity [µS/cm]<br>Alkalinity [mg/l]<br>Aluminum [mg/l] | Time: 10.08 am cloudy<br>Place: Tap in a house<br>Appearance: normal<br>Appearance of collection: normal<br><br>*Figure 88 Appendix C Tap in house (Author's own copyright)* |

*Table 43 Appendix C Parameter and their methods*

| Parameter | [Unit] | Method (APHA, 2017) | NB 512 |
|---|---|---|---|
| **pH** | [-] | 4500 Hb | 6.5-9.0 |
| **Turbidity** | [NTU] | 2510 B | 5 |
| **Permanganate Index** | [mg/l] | ISO 8467 | >4 high/ pure water <1* |
| **Conductivity** | [µS/cm] | 2510 B | 1500 |
| **Total Solids** | [mgST/l] | 2540 | / |
| **TDS** | [mgSTD/l] | 2540 C | 1000 |
| **TSS** | [mgSS7l] | 2540 | / |
| **Acidity** | [mg$CaCO_3$/l] | 2310 | / |
| **Alkalinity** | [mg/l] | 2320 B | 370 |
| **Aluminum** | [mg/l] | 3500 Al-B | 0.1-0.2 |
| **Calcium** | [mg$Ca^{2+}$/l] | 3500 Ca D | / |
| **Hardness** | [mg$CaCO_3$/l] | 2340 C | <500 soft |
| **Chloride** | [mg$Cl_-$/L c.I] | 4500 Cl- C | 250 |
| **Total iron** | [mgFe/L] | 3500 Fe D | 0.3 |
| **Magnesium** | [mg$Mg^{2+}$/L] | 3500 Mg B | 150 |
| **Mangan** | [mgMn/L] | 3500 Mn B | 0.1 |
| **Potassium** | [mg$K^+$/L] | 3500 K B | / |
| **Sodium** | [mg$Na^+$/L] | 3500 Na B | 200 |
| **Sulphates** | [mg$SO_4$/L] | 4500 SO42-E | 400 |
| **Ammonical Nitrogen** | [mgN-$NH_3$/l] | 4500 N-NH3 | 0.5 |
| **Carbonates** | [mg/l] | 2320 B | / |
| **Ferrous Iron** | [mg$Fe^{2+}$/l] | 3500 | / |
| **E. Coli** | [UFC/100 ml] | Filtermembrane 9221 | <1 |
| **Total Coliform** | [UFC/100 ml] | Filtermembrane 9222B | <1 |

*(Rodier J, Legube B, 2010)


*Figure 89 Appendix C Locations of sampling (Google Earth Pro 28.1.2017, scale 1:20m) (Data provided by the Water Cooperative)*


*Figure 90 (left) Appendix C Flow determination of the inlet of the plant (Author's own copyright) & Figure 91 (right) Appendix C Cleaning the basin 4th of June 2018 (Author`s own copyright)*

*Table 44 Appendix C Advantages and disadvantages of coagulants*

| INORGANIC COAGULANT | Advantages | Disadvantages | References |
|---|---|---|---|
| **Aluminum sulphate (alum)**<br><br>**$Al_2(SO_4)_3$** | +low costs<br>+pH range: 5.5-7.6<br>+adjustment with lime<br>+better color removal then Fe<br>+less sludge than lime<br>+no reddish color of the equipment compared to iron | -health risks associated<br>-sensitive temperature changes<br>-high dosage needed<br>-pH adjustment needed<br>-add salts | (Sillanpaä et al., 2017)<br>(TZOUPANOS & ZOUBOULIS, 2008)<br>(Park, Lim, Lee, & Woo, 2016) |
| **Sodium Aluminate** | +better color removal than Fe<br>+smaller dosage than alum | -health risks associated<br>-used in combination with alum | (Sillanpaä et al., 2017) |

| | | | |
|---|---|---|---|
| **$NaAlO_2$** | +better flocs in cold water than alum | -less in NOM removal compared to PAC and alum<br>-lime needed | (Kabsch-Korbutowicz, 2005)<br>(Chemical Publishing Company, 2011) |
| **Polyaluminum chloride (PAC)**<br><br>**$Al(OH)_n Cl_{3-n}$** | +consume less alkalinity than alum<br>+pH range bigger: 5.0-8.0<br>+less sulfate added to water<br>+less aluminum in the water<br>+works at low water temperature than alum<br>+less sludge<br>+removes DOC from water<br>*no lime needed | -2xprice alum<br>-not soft water | (Gebbie, 2001)<br>(TZOUPANOS & ZOUBOULIS, 2008)<br>(Park, Lim, Lee, & Woo, 2016) |
| **Ferrous sulphate**<br><br>**$FeSO_4$** | +pH range 4.5 and 7<br>+removes more DOC<br>+better in taste and odor removal than aluminum based<br>+used for softening (Mg and Fe) at high pH<br>+no so sensitive at pH change like lime | -coloring the basin<br>-high pH more effective<br>-need to add alkalinity (decrease acid capacity) | (Sillanpaä et al., 2017)<br>(Jarvis et al., 2012)<br>(Shammas & Wang, 2016a) |
| **Ferric Chloride**<br><br>**$FeCl_3$** | +better NOM removal capacities<br>+more and larger floc<br>+removes more DOC<br>+more compact sludge<br>+better in taste and odor removal than aluminum based | -coloring the basin<br>-need to add alkalinity (decrease acid capacity)<br>-add salts | (Sillanpaä et al., 2017)<br>(Jarvis et al., 2012)<br>(Shammas & Wang, 2016a) |
| **Ferric Sulphate**<br><br>**$Fe_2(SO_4)_3$** | +better NOM removal capacities<br>+more and larger floc<br>+better in taste and odor removal than aluminum based<br>+effective between 4-6 and 8.8 and 9.2 | -2xamount of $FeCl_3$ dosage<br>-coloring the basin<br>-need to add alkalinity (decrease acid capacity)<br>-add salts | (Sillanpaä et al., 2017)<br>(Shammas & Wang, 2016a) |
| **Lime**<br>**$Ca(OH)_2$** | + low costs<br>+increase the pH<br>+very effective<br>+no salts to the effluents | -over dosage end in poor quality<br>-sludge production | (Shammas & Wang, 2016a) |
| **Polymeric coagulant** | +enhance flocculation<br>+fasten reaction | -more expensive than organic<br>-control of dosage precisely | (Tzoupanos & Zouboulis, 2008)<br>(CHEMICAL PUBLISHING COMPANY, 2011) |
| **ORGANIC COAGULANT** | Advantages | Disadvantages | References |
| **Polymeric coagulants** | +reduce sludge volume 50-90 %<br>+sludge will contain less water<br>+no pH adjustment; do not affect the pH<br>+no salts added<br>+cheaper than inorganic | -control of dosage precisely | (TZOUPANOS & ZOUBOULIS, 2008)<br>(CHEMICAL PUBLISHING COMPANY, 2011) |

| | | | | |
|---|---|---|---|---|
| **1** | **Preparation solution for 21L** | | | |
| | Dosage 1kg/100l | | | |
| | Concentratio 10g AL2(S04)3 | | | |
| | 21L *10g Al2(S04)3 | 210g AL2(SO4)3/L | | in 21L bucket |
| **2** | **Concentration calculation for 200L barrel** | | | |
| Test1 | 2.41mg/l | Volumen= 2.41*200 000ml / 10 000ppm | = | 48.2ml |
| Test2 | 15mg/l | | = | 300ml |
| **3** | **Preparation for the tank operation 5.6.2018** | | | dosage 15mg/l |
| | inflow 4.6. = 9.91l/s | | | |
| | 12h*3600s *9.91l/s = 428 112L | | | |
| | x kg / 428 112L = 15mg/L | | = | 6.421kg in 100L |

*Figure 92 Appendix C: Calculation for the plant operation 4th /5th June 2018*

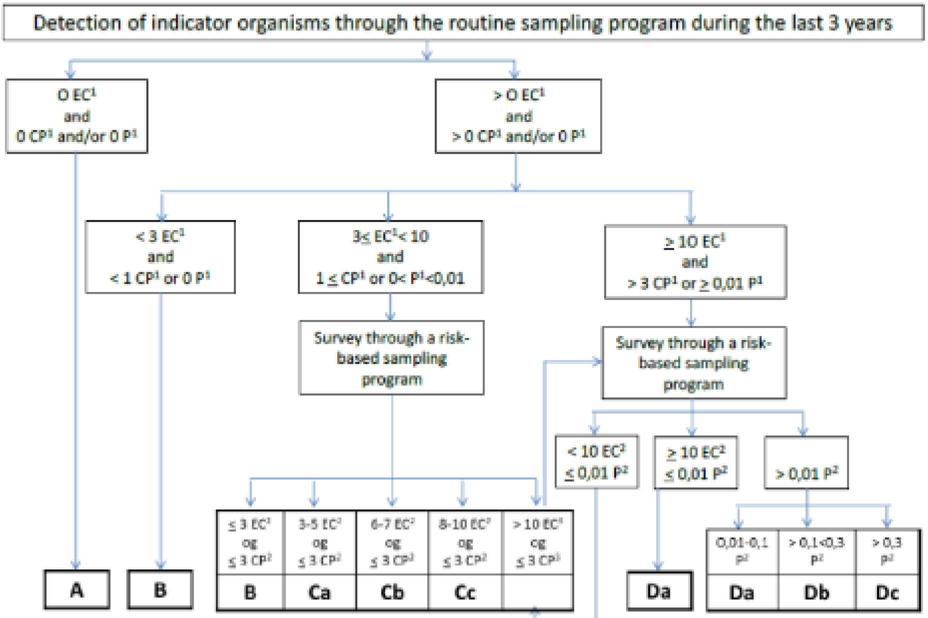
*Table 45 Appendix C Assumptions of the pathogen load of El Fuerte*

| **Assumptions pathogen load (Ferguson, Charles, & Deere, 2009)** | | **Reference** |
|---|---|---|
| **Livestock** | **Cows**<br>40 different owners with free cows on 2000 ha, (2 owner with each ¼ of the farm (1 each own 120 cows))<br>→*240 cows ¼ of area, total assumption 500 cows*<br>→ *40 % contribution to stream:* ***200 cows***<br>**Horses**<br>>2 horses each owner<br>→*1-2 horses one farmer, total assumption 10 horses* →*20 % contribution:* ***2 horses*** | Personal conversation with people taking care of livestock (2018, 10th of April) |
| **Wildlife** | **Deer**<br>→*Density (per $km^2$) 0.5* → *10 deer, 40 %:* ***4 deer***<br>**Dogs (feral)**<br>→*Density (per $km^2$) 0.25*→ *5 dogs, 40 %:* ***2 dogs***<br>(**Puma, bear, jaguar, monkeys**) **seldom in the area* | SUBGOBERNACION PROVINCIA FLORIDA (2014) and Inspection (2018, 9th April) |
| **Industry** | No | |
| **Agriculture** | No | |
| **Residents** | No | |
| **Infrastructure** | No | |
| **Wastewater treatment plant** | No | |


*Figure 93 Appendix C Area of the expected free cows (Author`s own copyright)*

*Table 46 Appendix C Pathogen load calculations El Fuerte*

| **Livestock** | Cows | Horses | Deers | Dogs (feral) | Notes |
|---|---|---|---|---|---|
| Number of animals | 200 | 2 | 2 | 2 | |
| Faeces per cow [kg/day] | 63 | 28 | 1 | 0.5 | |
| Density faeces [g/l] | 400 | 400 | 400 | 400 | Assumption: 400g/l= 0.4g/cm$^3$ |
| Total faeces [m$^3$/day] | 31.5 | 0.14 | 0.005 | 0.0025 | |
| Q faeces [m$^3$/s] | 0.00036458 | 1.62E-06 | 5.78E-08 | 2.89E-08 | |
| Dilution factor (rainy) | 0.00046741 | 2.07E-06 | 7.42E-08 | 3.71E-08 | |
| Dilution factor (dry) | 0.00140224 | 7.99E-06 | 2.85E-07 | 1.43E-07 | |
| **Assumption Qriver [m$^3$/s]** | | El Fuerte | | | |
| A river =1.5*0.35= 0.525m$^2$ | | | | | 15m$^3$/s measured in rainy season |
| A pipe = (20.32/2)$^2$*pi= 0.0324m$^2$ | | | | | |
| 0.0324/0.015 = 0.525/x | X= 0.243 m$^3$/s | | | | **Case Dry** : less diltution, more conc., |
| Qriver+Qpipe= 0.243+0.015= 258 l/s ~260l/s | | | Qdry [m$^3$/s] | 0.26 | but not everything come to source |
| Dry season: 6 months May-Oc | | 27.42mm/month mean | | x3 factor | |
| Rainy season: 6 months Nov-April | | 81.67mm/ month mean | | | **Case Rainy** : more diluted, |
| | | | Qrainy [m$^3$/s] | 0.78 | but all faeces will be drained to the plant |
| La Figuritas Qpipe= 0-1l/s | no info about Qriver | | | | La Figuritas and Alisos are not considered, |
| Alisos Qpipe= 2-3l/s | no info about the activites in catchment area | | | | both have to be added to the stream |
| Case | Rainy season | | Dry season | | |
| **Pathogens** | Faeces [n/l] | Concentration in raw water [n/l] | Faeces [n/l] | Concentration in raw water [n/l] | |
| Giardia | 4.8E+08 | 22.54E+04 | 4.8E+08 | 67.71E+04 | |
| Cryptosporidium | 8.4E+06 | 0.39E+04 | 8.4E+06 | 1.18E+04 | |
| Campylobacter | 16E+06 | 0,75E+04 | 16E+06 | 2.25E+04 | |
| E.Coli | data from measuremet | | | | |
| Salmonella | not considered in the study, to small | | | | |
| Norovirus | only domestic waste water | | | | |
| Rotavirus | only domestic waste water | | | | |




[1]Detection of indicator (EC – *E.Coli*, CP – *Clostridum Perfringens*) over indicated value (number/100 ml) one or several times during the last 3 years

[2]Average concentration (number/100 ml) of indicator over the sampling period or detection of indicated level in more than 1/6 of the samples (16,7 %) over the period. For parasites it is sum of Giardia and Cryptosporidium/100 ml

[3] Or > 20 EC/100 ml or > 6 CP in single samples

*Figure 94 Appendix C Determination of raw quality level STEP 1 MBA (Ødegaard H., 2014)*

| Size of water utility | | Raw water quality level | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| < 1000 pe | Barrier level required | 3,0b + 3,0v + 2,0p | 4,0b + 4,0v + 2,0p | a. 4,5b + 4,5v + 2,5p<br>b. 4,5b + 4,5v + 3,0p<br>c. 4,5b + 4,5v + 3,5p | a. 5,0b + 5,0v + 3,0p<br>b. 5,0b + 5,0v + 3,5p<br>c. 5,0b + 5,0v + 4,0p |
| 1000 – 10.000 pe | | 3,5b + 3,5v + 2,5p | 4,5b + 4,5v + 2,5p | a. 5,0b + 5,0v + 3,0p<br>b. 5,0b + 5,0v + 3,5p<br>c. 5,0b + 5,0v + 4,0p | a. 5,5b + 5,5v + 3,5p<br>b. 5,5b + 5,5v + 4,0p<br>c. 5,5b + 5,5v + 4,5p |
| > 10.000 pe | | 4,0b + 4,0v + 3,0p | 5,0b + 5,0v + 3,0p | a. 5,5b + 5,5v + 3,5p<br>b. 5,5b + 5,5v + 4,0p<br>c. 5,5b + 5,5v + 4,5p | a. 6,0b + 6,0v + 4,0p<br>b. 6,0b + 6,0v + 4,5p<br>c. 6,0b + 6,0v + 5,0p |

*Figure 95 Appendix C Barrier level required depending on the size of systems and raw water quality level STEP 2 MBA (Ødegaard H., 2014)*

| Category of barrier action | Barrier actions in detail | Log-credit |
|---|---|---|
| Reduction of the pollution load to the water source | Closing of all sewage discharges directly to the water source and to river systems that leads directly to the source | 0,75b + 0,75v + 0,5p |
| | Implementation of closed sewage systems (closed tank) for all sewage effluents in the catchment area, or watertight sewage systems bringing sewage out of the catchment area. | 0,5b + 0,5v + 0,25p |
| | Erecting fences for the prevention of farm animals, dogs etc. to come in direct contact with the source water and provision of garbage containers (including containers for dog feces) in the catchment area | 0,25b + 0,25v + 0,15p |
| Restrictions in the activity allowed in the water source and the catchment area | Introducing a ban (or restrictions) on keeping grazing farm animals in the catchment area | 0,75b + 0,75v + 0,5p |
| | Introducing a ban on construction and other potentially polluting activities in the catchment area, e.g. motor traffic | 0,25b + 0,25v + 0,15p |
| | Introducing a ban (or restrictions) on the use of watersports, bathing or other types of recreation in the water source, e.g. motor traffic | 0,25b + 0,25v + 0,15p |
| Measures connected to the water intake in the lake | Lowering of the water intake to a depth that ensures that the intake is below the thermocline except in the circulation periods | 0,5b + 0,5v +0,25p |
| | Moving the raw water intake to such a position that it can be documented through hydraulic studies that fecal pollution from sewage and animals does not affect the water quality art the intake | 0,25b +0,25v + 0,15p |
| **Absolut maximum summarized log-credit for barrier in water source and catchment** | | **2,0b + 2,0v + 1,25p** |

*Figure 96 Appendix C Log-credit for new physical and restrictive actions in lakes and catchment area STEP 3 MBA (Ødegaard H., 2014)*

| Particle separation method | Log-credit |
|---|---|
| Rapid sand filtration without coagulation (filtration rate < 7,5 m/h)[1] | 0,5b +0,25v +0,5p |
| Membrane (MF) filtration[2] | 2,0b + 1,0v + 2,0p |
| Membrane (UF) filtration[3] | 2,5b + 2,0v + 2,5p |
| Membrane (NF) filtration [4] | 3,0b + 3,0v + 3,0p |
| Slow sand filtration (filtration rate < 0,5 m/h) | 2,0b + 2,0v + 2,0p |
| Coagulation/direct filtration (media-filter)[5] | 2,25b + 1,5v + 2,25p |
| Coagulation/direct filtration (media-filter)[6] | 2,5b + 2,0v + 2,5p |
| Coagulation + sedimentation (or flotation) + filtration[5] | 2,5b + 1,75v + 2,5p |
| Coagulation + sedimentation (or flotation) + filtration [6] | 2,75b + 2,25v + 2,75p |
| Coagulation/membrane MF filtration[6] | 3,0b + 2,5v + 3,0p |
| Coagulation/membrane UF filtration[6] | 3,0b + 3,0v + 3,0p |

[1] Also valid for biofilters, ion exchange filters, activated carbon filters and calcium carbonate filters
[2] Provided nominal membrane pore diameter < 100 nm
[3] Provided nominal membrane pore diameter < 40 nm
[4] Provided nominal membrane pore diameter < 5 nm
[5] Provided turbidity in produced water < 0,2 NTU.
[6] Provided high coagulant dosage and good operation control to ensure turbidity in produced water < 0,1 NTU

*Figure 97 Appendix C Log-credit for particle separation processes in water treatment STEP 4 MBA (Ødegaard H., 2014)*

| Category of barrier actions | Operation control monitoring (and follow-up) actions | Deduction in log-credit if monitoring measure is lacking |
|---|---|---|
| On-line monitoring of treated water quality with follow-up actions to comply with set limit values[1] | For on-line monitoring of treated water turbidity, color or other parameter suitable for process control: | |
| | • is lacking | 40% |
| | • is present, activating an alarm when over-shooting a set-point (alarm value) leading to manual correction of process conditions (e.g. adjustments of pH, coagulant dosage etc.) so that normal operation is restored | 20% |
| | • is present, activating an alarm when over-shooting a set-point (alarm value) leading to manual closing of raw water supply until the cause of abnormality is found and normal operation is restored | 10 % |
| | • is present activating an automatic closing of raw water supply until the cause of abnormality is found and normal operation is restored | 0 % |

*Figure 98 Appendix C Deduction of the log-credit STEP 4 MBA (Ødegaard H., 2014)*

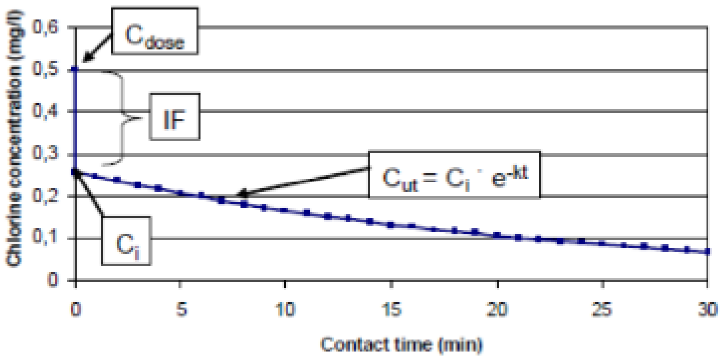



*Figure 99 Appendix C Schematic description chlorine degradation as a basis for the calculation of Ct STEP 5 MBA (Ødegaard H., 2014)*

| Mixing condition (extent of plug flow (PF) in each chamber) | Hydraulic factor | | Description of each chamber in contact tank | Serial factor, $F_n$ Chambers in series | | |
|---|---|---|---|---|---|---|
| | $t_{10}/T$[1] | $t_m/T$[2] | | 1 | 2 | 3 |
| No PF (complete mixing) | 0,1 | 0,3 | No baffles, agitated tank, high in- and out-velocities, low length/ width ratio in tank (≤1) | 1,0 | 2,0 | 2,5 |
| Poor PF | 0,3 | 0,4 | No baffles inside tank, single inlets and outlets in tank, length/ width ratio in tank >1 | 1,0 | 1,8 | 2,0 |
| Average PF | 0,5 | 0,5 | Baffled inlet or outlet, some baffles inside tank and possibly multiple inlets and outlets, length/ width ratio in tank >4 | 1,0 | 1,5 | 1,8 |
| Quite good PF | 0,7 | 0,7 | Baffled inlet, serpentine baffles inside tank to increase length/ width ratio to > 6 | 1,0 | 1,3 | 1,4 |
| Very good PF | 0,9 | 0,9 | Baffled inlet, serpentine or perforated plate baffles inside tank. High length/ width ratio (>10) | 1,0 | 1,1 | 1,1 |
| Perfect PF | 1,0 | 1,0 | Very high length/ width ratio (>20). Pipeline flow | 1,0 | 1,0 | 1,0 |

[1]To be used in Ct-calculation [2]To be used in calculation of k, $C_i$ and $C_{out}$ (see below)

*Figure 100 Appendix C Recommended values for hydraulic factor and serial factor STEP 5 MBA (Ødegaard H., 2014)*

# Appendix D Results

| | | | | | |
|---|---|---|---|---|---|
| Date | 8.5.2018 and 9.5.2018 | | | | |
| Water | influent in the plant = 10L | | | | |
| Coagulant | $Al_2(SO_4)_3 \cdot 14\ H_2O$ | | | | |
| Conditions in Samaipata | 1kg $Al_2(SO_4)_3$ in 100L | | | | |
| **1** | Preparation of the test | | | | |

Concentration: $\frac{1\ kg\ Al_2(SO_4)_3 \cdot 1000 g \cdot 1000 mg}{100 L \cdot 1 kg \cdot 1 g} = \frac{10000\ mg\ Al_2(SO_4)_3}{L} = \frac{10\ g\ Al_2(SO_4)_3}{L}$

Preparation for 0.5 [L]: $\frac{0.5\ L \cdot 10 g\ Al_2(SO_4)_3}{1 l} = \frac{5\ g\ Al_2(SO_4)_3}{L}$

| Date | Test 1: 8.5.2018 | | Test 2: 9.5.2018 | | |
|---|---|---|---|---|---|
| Test | Concentration [mg Al2(SO4)3/L] | Volume [ml] | Concentration [mg Al2(SO4)3/L] | Volume [ml] | Volume for a medium of 800ml |
| 1 | 2.41 | 0.2 | 15 | 1.2 | |
| 2 | 5 | 0.4 | 20 | 1.6 | |
| 3 | 10 | 0.8 | 25 | 2.0 | C1*V1=C2*V2 |
| 4 | 12.5 | 1.0 | / | | |
| 5 | 15 | 1.2 | / | | |
| 6 | 20 | 1.6 | / | | |

**2** Reaction of coagulant in the range drinkingwater norm 6-9 pH

800ml — pH does not drop 6

| Test | Volume [ml] | pH [-] >6 | volume for a medium of 800ml |
|---|---|---|---|
| 1 | 0.2 | 6.92 | |
| 2 | 0.4 | 6.82 | all above 6 |
| 3 | 0.8 | 6.61 | all possible to use |
| 4 | 1.0 | 6.52 | |
| 5 | 1.2 | 6.38 | |
| 6 | 1.6 | 6.12 | |

**3** Jar test

| PROCEDURE | Rotation |
|---|---|
| 1 min rapid mixing | 154 RPM |
| 10 min slow mixing | 40 RPM |
| 10 min sedimentation | / |

**4** pH and turbidity after sedimentation

| Test | Test 1: 8.5.2018 | | | Test 2: 9.5.2018 | | |
|---|---|---|---|---|---|---|
| | T= 60 Min | | | T=40-45min | | |
| | Volume [ml] | pH[-] | Turbidity [NTU] | Volume [ml] | pH[-] | Turbidity [NTU] |
| initial | 0 | 6.99 | 5.31 | 0 | 7.3 | 6.073 |
| 1 | 0.2 | 6.83 | 4.48 | 1.2 | 6.81 | 7.97 |
| 2 | 0.4 | 6.76 | 5.08 | 1.6 | 6.42 | 0.63 |
| 3 | 0.8 | 6.61 | 6.28 | 2.0 | 6.08 | 0.3 |
| 4 | 1.0 | 6.47 | 7.11 | | | |
| 5 | 1.2 | 6.45 | 7.2 | | | |
| 6 | 1.6 | 6.24 | 0.19 | | | |
| | | >6pH | | | | |

Flocculation observation

| Test | Test 1: 8.5.2018 | | Test 2: 9.5.2018 | |
|---|---|---|---|---|
| | Volume [ml] | Observations | Volume [ml] | Observations |
| 1 | 0.2 | no flocs, turbid | 1.2 | little flocs, turbid |
| 2 | 0.4 | no flocs, turbid | 1.6 | flocs, sedimentation, clear water, clear separation. more sedimentation than with 2.0 |
| 3 | 0.8 | no flocs, turbid | 2.0 | flocs, sedimentation, clear water, clear separation. in the beginning more flocs than with 1.6 ml |
| 4 | 1.0 | no flocs, turbid | | |
| 5 | 1.2 | small flocs, turbid | | |
| 6 | 1.6 | flocs, sedimentation, clear water, clear separation | | |

**5** Filtration

| Test | Volume [ml] | $Turbidity_{initial}$ [NTU] | Turbidity [NTU] |
|---|---|---|---|
| 5 | 1.2 | 7.2 | 1.025 |
| 6 | 1.6 | 0.19 | 0.015 |

*Figure 101 Appendix D Jar test Aluminum Sulfate 8. /9.5.2018*

| | | | | | | |
|---|---|---|---|---|---|---|
| Date | 23.5.2018 | | | | | |
| Water | influent in the plant = 10L | | | | | |
| Coagulant | Al2(SO4)3 * 14 H2O | | | | | |
| Conditions in Samaipata | | 1kg Al2(SO4)3 in 100L | | | | |
| 1 | **Preparation of the test/ Concentration** | | | | | |

$$\frac{1\ kg\ Al2(SO4)3 * 1000g * 1000mg}{100L * 1kg * 1g} = \frac{10000\ mg\ Al2(So4)3}{L} = \frac{10\ g\ Al2(SO4)3}{L}$$

$$\frac{0.5\ L * 10g\ Al2(SO4)3}{1l} = \frac{5\ g\ Al2(SO4)3}{L}$$

C= 5000ppm=5000mg Al2(S04)3/L

concentration 1/2 = 2* Volume

volume for a medium of 800ml

C1*V1=C2*V2

| Sample | Concentration [mg Al2(S04)3/L] | Volume [ml] |
|---|---|---|
| 1 | 2.5 | 0.4 |
| 2 | 5 | 0.8 |
| 3 | 10 | 1.6 |
| 4 | 12.5 | 2.0 |
| 5 | 15 | 2.4 |
| 6 | 20 | 3.2 |

| 2 | Jartest: Coagulation and Flocculation | |
|---|---|---|
| Process | Time | Rotation |
| Rapid Mixing | 1Min | 200 RPM |
| Slow Mixing | 10 Min | 40 RPM |
| Sedimention | 10 Min | / |
| Sedimention | 10 Min | / |

| 3 | Sedimentation, Turbidity and pH determination |
|---|---|
| Turbidity initial | 6,5 NTU |
| pH initial | 7.58 |

| Test | Concentration [mg Al2(S04)3/L] | Volume [ml] | pH [-] | Turbidity [NTU] | pH [-] | Turbidity [NTU] |
|---|---|---|---|---|---|---|
| | | | t= 10 Min | | t= 20 Min | |
| 1 | 2.5 | 0.4 | 6.55 | 2.93 | 6.63 | 2.63 |
| 2 | 5 | 0.8 | 6.54 | 4.17 | 6.68 | 2.84 |
| 3 | 10 | 1.6 | 6.33 | 3.87 | 6.37 | 3.53 |
| 4 | 12.5 | 2.0 | 6.18 | 0.59 | 6.2 | 0.09 |
| 5 | 15 | 2.4 | 5.87 | 0.44 | 5.89 | 0.09 |
| 6 | 20 | 3.2 | 5.19 | 3.63 | 5.32 | 3.38 |

pH between 6.0 and 9.0

Oberservation: 4 2nd best flocs — 4 and 5 have shown best reaction

5 best and strongest flocs

6 less flocs

Result: Optimal dosage 10-12.5-15

Attention to the pH, nummer 5 can not be used to less the ph decrease

Filtration

| | Color | Turbidity |
|---|---|---|
| Sedimentation t=20min | 20 | 0.09 |
| Additionally filtration | 0 | 0.0 |

*Figure 102 Appendix D Jar Test Aluminum Sulfate 23.5.2018*

| | |
|---|---|
| Date | 28.5.2018 |
| Water | influent in the plant = 10L |
| Coagulant | Al2(SO4)3 * 14 H2O |
| Conditions in Samaipata | 1kg Al2(SO4)3 in 100L |

**1 Preparation of the test/ Concentration**

$$\frac{1\ kg\ Al2(SO4)3*1000g*1000mg}{100L*1kg*1g} = \frac{10000\ mg\ Al2(So4)3}{L} = \frac{10\ g\ Al2(SO4)3}{L}$$

$$\frac{0.5\ L\ *\ 10g\ Al2(S04)3}{1l} = \frac{5\ g\ Al2(S04)3}{L}$$

C= 5000ppm=5000mg Al2(S04)3/L

Concentration 1/2 = 2* Volume

| Glass | Concentration [mg Al2(S04)3/L] | Volume [ml] | Volume for a medium of 800ml |
|---|---|---|---|
| 1 | 2.5 | 0.4 | C1*V1=C2*V2 |
| 2 | 5 | 0.8 | |
| 3 | 10 | 1.6 | |
| 4 | 12.5 | 2.0 | |
| 5 | 15 | 2.4 | |
| 6 | 20 | 3.2 | |

**2 Jar test: Coagulation and Flocculation**

| Process | Time | Rotation |
|---|---|---|
| Rapid Mixing | 1Min | 200 RPM |
| Slow Mixing | 10 Min | 40 RPM |
| Sedimention | 10 Min | / |
| Sedimention | 10 Min | / |

**3 Sedimentation, Turbidity and pH determination**

Turbidity initial 6.22

pH initial 7.35

| Test | Concentration [mg Al2(S04)3/L] | Volume [ml] | pH [-] | Turbidity [NTU] | pH [-] | Turbidity [NTU] |
|---|---|---|---|---|---|---|
| | | | t= 10 Min | | t= 20 Min | |
| 1 | 2.5 | 0.4 | 7.2 | 6.49 | 6.73 | 6.47 |
| 2 | 5 | 0.8 | 6.92 | 7.06 | 6.78 | 6.95 |
| 3 | 10 | 1.6 | 6.57 | 8.03 | 6.41 | 7.82 |
| 4 | 12.5 | 2.0 | 6.22 | 3.72 | 6.12 | 2.22 |
| 5 | 15 | 2.4 | 5.98 | 3.62 | 5.97 | 2.4 |
| 6 | 20 | 3.2 | 5.31 | 8.96 | 5.27 | 8.02 |

pH between 6.0 and 9.0

Oberservation: 4,5,6 best flocs
4 minimum

Result: Optimal dosage 10-12.5

Filtration

| | Color | Turbidity |
|---|---|---|
| Sedimentation t=20min | 22 | 2.22 |
| Additionally Filtration | 1.1 | 23 |

*Figure 103 Appendix D Jar Test Aluminum Sulfate 28.5.2018*

| | | | | | | |
|---|---|---|---|---|---|---|
| Date | 21.5.2018 | | | | | |
| Place | CASA Laboratory | | | | | |
| Source | Influent in the plant | | | | | |
| Coagulant | **Lime Ca(OH)2 and Al2(SO4)3** | | Al2(SO4)3 * 14 H2O | | | |
| Procedure | Adjustment of pH with lime and floccualtion with ALUM | | | | | |
| Concentration in the plant | 1kg Al2(SO4)3 in 100L | | | | | |
| 1 | Preparation of the test/ Concentration | | | | | |

$$\frac{1\,kg\,Al2(SO4)3*1000g*1000mg}{100L*1kg*1g}=\frac{10000\,mg\,Al2(SO4)3}{L}=\frac{10\,g\,Al2(SO4)3}{L}$$

$$\frac{0.5\,L\,*10g\,Al2(SO4)3}{1l}=\frac{5\,g\,Al2(SO4)3}{L}$$

C= 5000ppm=5000mg Al2(S04)3/L

Concentration 1/2 = 2* Volume

Volume for a medium of 800ml

C1*V1=C2*V2

| Glass | Concentration [mg Al2(S04)3/l] | Volume [ml] |
|---|---|---|
| 1 | 2.5 | 0.4 |
| 2 | 5 | 0.8 |
| 3 | 10 | 1.6 |
| 4 | 12.5 | 2.0 |
| 5 | 15 | 2.4 |
| 6 | 20 | 3.2 |

| 2 | Adjustment pH with lime |
|---|---|
| pH shall increase to 9 pH | |
| Lime Ca(OH)2 solution | 10g/200ml<br>10gLime/(10gLime+200mlH20) *100 = 4.76% = 5.0%<br>5.0% solution |
| Instruments | Hack TitraStir — mixing 30 min |

| pH [-] | Volume 5.0% lime solution 200ml [ml] |
|---|---|
| 7.58 | initial |
| 9.76 | 0.1 |
| 10.18 | 0.2 |
| for 800ml -->0.32ml | for 9.0 |
| determinted pH | measured 9.58 |
| 6 glasses with 800ml are prepared with 0.32ml Lime each | |

| 3 | Jartest: Coagulation and Flocculation | |
|---|---|---|
| Process | Time | Rotation |
| Rapid Mixing | 1Min | 200 RPM |
| Slow Mixing | 10 Min | 40 RPM |
| Sedimention | 10 Min | / |
| Sedimention | 10 Min | / |

| **4** | Sedimentation, Turbidity and pH determination | | | | | |
|---|---|---|---|---|---|---|
| Test | Concentration [mg Al2(S04)3/L] | Volume [ml] | pH [-] | Turbidity [NTU] | pH [-] | Turbidity [NTU] |
| | | | t= 10 Min | | t= 20 Min | |
| 1 | 2,5 | 0.4 | 9.42 | 9.59 | 9.34 | 9.44 |
| 2 | 5 | 0.8 | 9.25 | 8.77 | 9.22 | 8.49 |
| 3 | 10 | 1.6 | 9.12 | 8.99 | 8.97 | 8.69 |
| 4 | 12,5 | 2.0 | 8.73 | 9.03 | 8.81 | 8.43 |
| 5 | 15 | 2.4 | 8.72 | 9.23 | 8.74 | 8.85 |
| 6 | 20 | 3.2 | 7.39 | 9.21 | 7.47 | 9.11 |

ph between 6.0 and 9.0

Inital turbidity 6.5 NTU — All over 6.5!, after 20 Min less NTU, high could be Lime

ph after adjustment 9.58 — All lower, small increase some after 20Min

Observation: Slow mixing 2-11 min almost nothing visible, some particles

Almost all the same reaction

No flocs?

*Figure 104 Appendix D Jar Test Lime and Aluminum Sulfate 21.5.2018*

| | | | | | | |
|---|---|---|---|---|---|---|
| Date | 28.5.2018 | | | | | |
| Water | influent in the plant = 10L | | | | | |
| Coagulant | FeSO4 | | | | | |
| Conditions in Samaipata | | 1kg in 100L | | | | |
| 1 | Preparation of the test/ Concentration | | | | | |

$$\frac{1\ kg\ FeSO4*1000g*1000mg}{100L*1kg*1g} = \frac{10000\ mg\ FeSO4}{L} = \frac{10\ FeSO4}{L}$$

$$\frac{0.5\ L\ *10g\ FeSO4}{1l} = \frac{5\ g\ FeSO4}{L}$$

C= 5000ppm=5000mg FeSO4/L    Concentration 1/2 = 2* Volume

Dilution of 2.6042g in 0.5 water

| Glass | Concentration [mg FeSO4/L] | Volume [ml] | Volume for a medium of 800ml |
|---|---|---|---|
| 1 | 2,5 | 0.4 | C1*V1=C2*V2 |
| 2 | 5 | 0.8 | |
| 3 | 10 | 1.6 | |
| 4 | 12,5 | 2.0 | |
| 5 | 15 | 2.4 | |
| 6 | 20 | 3.2 | |

| 2 | Jartest: Coagulation and Flocculation | |
|---|---|---|
| Process | Time | Rotation |
| Rapid Mixing | 1Min | 200 RPM |
| Slow Mixing | 10 Min | 40 RPM |
| Sedimention | 10 Min | / |
| Sedimention | 10 Min | / |

3 Sedimentation, Turbidity and pH determination

pH initial 7.4

Turbidity inital 5.22

| Test | Concentration [mg FeSO4/L] | Volume [ml] | pH [-] | Turbidity [NTU] | pH [-] | Turbidity [NTU] |
|---|---|---|---|---|---|---|
| | | | t= 10 Min | | t= 20 Min | |
| 1 | 2,5 | 0.4 | 7.11 | 5.8 | 6.95 | 5.81 |
| 2 | 5 | 0.8 | 6.95 | 6.18 | 6.91 | 6.11 |
| 3 | 10 | 1.6 | 6.76 | 6.73 | 6.76 | 6.8 |
| 4 | 12,5 | 2.0 | 6.67 | 7.02 | 6.70 | 7.05 |
| 5 | 15 | 2.4 | 6.65 | 7.48 | 6.64 | 7.44 |
| 6 | 20 | 3.2 | 6.58 | 8.06 | 6.56 | 8.06 |
| | ph between 6.0 and 9.0 | | | | | |

Oberservation: No result visible; increase of turbidity due to coagulant dosage

Result: Dosage needs to be increased

*Figure 105 Appendix D Jar Test $FeSO_4$ 28.5.2018*

| | | |
|---|---|---|
| Date | 23.5.2018 | |
| Water | Influent in the plant = 10L | |
| Coagulant | Ferric Chloride | FeCl3*6H20 |
| Conditions in samaipata | | 1kg in 100L |

| 1 | Preparation of the test/ Concentration |
|---|---|

$$\frac{1\ kg\ FeCl3*1000g*1000mg}{100L*1kg*1g} = \frac{10000\ mg\ FeCl3}{L} = \frac{10\ FeCl3}{L}$$

$$\frac{0.5\ L\ *\ 10g\ FeCl3}{1l} = \frac{5\ g\ FeCl3}{L}$$

C= 5000ppm=5000mg FeCl3/L

Concentration 1/2 = 2* Volume

Dilution of 2.6042g in 0.5 water

| Glass | Concentration [mg FeCl3/L] | Volume [ml] |
|---|---|---|
| 1 | 2,5 | 0.4 |
| 2 | 5 | 0.8 |
| 3 | 10 | 1.6 |
| 4 | 12,5 | 2.0 |
| 5 | 15 | 2.4 |
| 6 | 20 | 3.2 |

Volume for a medium of 800ml
C1*V1=C2*V2

| 2 | Jartest: Coagulation and Flocculation | |
|---|---|---|
| Process | Time | Rotation |
| Rapid Mixing | 1Min | 200 RPM |
| Slow Mixing | 10 Min | 40 RPM |
| Sedimention | 10 Min | / |
| Sedimention | 10 Min | / |

| 3 | Sedimentation, Turbidity and pH determination |
|---|---|
| pH initial | 6.74 |
| Turbidity inital | 6.73 |
| Color inital | 88 |

| Test | Concentration [mg FeCl3/L] | Volume [ml] | pH [-] t= 10 Min | Turbidity [NTU] t= 10 Min | pH [-] t= 20 Min | Turbidity [NTU] t= 20 Min |
|---|---|---|---|---|---|---|
| 1 | 2,5 | 0.4 | 6.56 | 4.94 | 6.75 | 4.38 |
| 2 | 5 | 0.8 | 6.57 | 4.96 | 6.6 | 4.84 |
| 3 | 10 | 1.6 | 6.46 | 5.47 | 6.42 | 5.27 |
| 4 | 12,5 | 2.0 | 6.36 | 5.85 | 6.35 | 5.63 |
| 5 | 15 | 2.4 | 6.32 | 6.00 | 6.29 | 5.93 |
| 6 | 20 | 3.2 | 6.13 | 0.79 | 6.03 | 0.58 |

ph between 6.0 and 9.0

Oberservation: 5 and 6 have shown the best result

Result: Optimal dosage 12.5-15

Attention to the pH, nummer 6 is close to the limit

For color ALUM better

For turbitity FeCl3 better

Filtration

| | Color | Turbidity |
|---|---|---|
| Initial | 88 | 6.73 |
| S5 after T=20min | 149 | 5.93 |
| S4 after T=20min and filtration | 128 | 4.63 |

| | Color | Turbidity |
|---|---|---|
| Initial | 88 | 6.73 |
| Only Filtration of the water | 71 | 2.83 |

Only filtration reduced the turbidity 3/4!

*Figure 106 Appendix D Jar Test Ferric Chloride 23.5.2018*

*Table 47 Appendix D: Legend and considerations for the Risk Matrix at the intake of Samaipata*

| Fecal indicator pathogens | Pathogen type | Indicator | Discussion |
|---|---|---|---|
| **E. Coli** | Bacteria | X1 | Once per day, concentration inlet, harmful to a large population, high health significance and infection, animal source |
| **Campylobacter** | Bacteria | X2 | Once per week, harmful large population, high health significance, animal source |
| **Cryptosporidium** | Protozoa | X3 | Once a day, harmful large population, high health significance and infectivity, animal source |
| **Giardia** | Protozoa | X4 | Once per week, harmful to large population, high infection, moderate persistence, animal source |
| **Salmonella** | Bacteria | X5 | Once per year, harmful to a large population, high significance, low infectivity |
| **Viruses** | Virus | X6 | Once per week, harmful to a large population, high significance, high infectivity, potentially from animals' source |